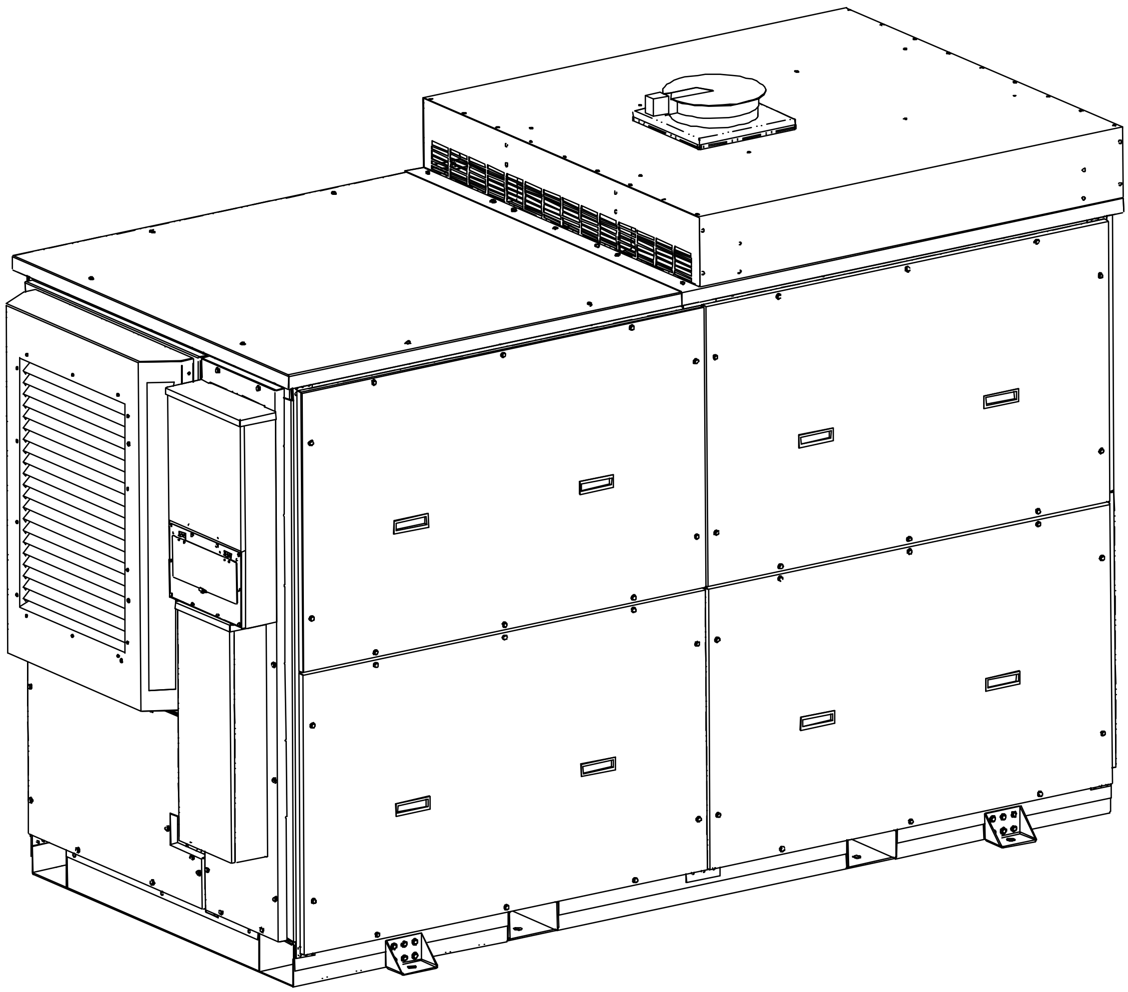
CAPSTONE TURBINE CORPORATION

CAPSTONE C200 MICROTURBINE

TECHNICAL REFERENCE



410066 Rev C (June 2009)

Capstone Turbine Corporation

21211 Nordhoff Street • Chatsworth • CA • 91311 • USA

Telephone: (818) 734-5300

Facsimile: (818) 734-5320

Website: www.capstoneturbine.com

Capstone Technical Support

Toll Free Telephone: (866) 4-CAPSTONE or (866) 422-7786

Service Telephone: (818) 407-3600 • Fax: (818) 734-1080

E-mail: service@capstoneturbine.com

Table of Contents

SUBJECT PAGE

List of Figures

List of Tables

TABLE PAGE

CHAPTER 1: INTRODUCTION

Document Overview

This document is intended to give the reader a general description of the Capstone C200 MicroTurbine®. It includes a description of the major components and how they interact, detailed product performance, and basic application guidance. It is intended to be used by a variety of audiences, and provides references to additional information which may be needed to answer more detailed questions. Within this document, you will find hyperlinks that will direct you to related topics in sections you are referencing. Clicking these links will move the document to that section.

Below are a few examples of how this technical reference may be useful to selected audiences:

Architects, Engineers, and other Equipment Specifiers

Capstone microturbines are gas turbines with a variety of unique features compared with traditional forms of electric generation. This technical reference provides an overview of how the Capstone C200 operates, along with detailed performance information. This information is intended to assist project specifiers and designers to properly select the right Capstone C200 microturbine for a given application, and then complete a system design that includes the selected microturbine(s). Other documents that may be relevant for this purpose are:

- C200 Product Specification (460045) – This document summarizes the key performance characteristics of the C200 microturbine, and is the basis for Capstone's standard warranty. The Product Specification information has precedence in the case of any conflict with this technical reference.
- C200 Outline and Installation (O&I) Drawings (523005) – Detailed dimensions, weights, and other product installation information are contained in this document. The O&I drawings take precedence in case of any conflict with this technical reference.
- Fuel Requirements Technical Reference (410002) – The fuel requirements document provides detailed information about fuel characteristics required for proper operation of any Capstone microturbine.
- Emissions Technical Reference (410065) – The emissions for all Capstone distributed generation products are summarized in this technical reference to address local air permitting requirements.

Capstone Microturbine Owners and Operators

Owners and operators may find the technical information in this document useful to understand the basics of how their Capstone C200 microturbine works. Capstone microturbines are gas turbines with a variety of unique features compared with traditional forms of electric generation. This document provides information that will properly set expectations as to performance and behavior of the C200 microturbine. Other documents that may be relevant for this purpose are:

- C200 User's Manual (400008) – The C200 User's Manual provides explanations of how to interact with the C200 microturbine (including details of the local user display), as well as general maintenance guidance and simple troubleshooting.
- CRMS Technical Reference User's Edition (410013) – The user edition Capstone Remote Monitoring Software (CRMS) provides more detailed interaction with the C200 than the local display alone. The CRMS User's Edition explains how to operate this optional software.
- C200 Product Specification (460045) – This document summarizes the key performance characteristics of the C200 microturbine, and is the basis for Capstone's standard warranty. The Product Specification information has precedence in the case of any conflict with this technical reference.

Capstone Installers and Service Personnel

The C200 Technical Reference is intended to be a "hub" from which installers and service technicians can find all relevant technical details regarding the troubleshooting, installation, sizing, and interconnection of the equipment. Other documents that may be relevant for this purpose are:

- C200 O&I Drawings (523005) – Detailed dimensions, weights, and other product installation information are contained in this document. The O&I drawings take precedence in case of any conflict with this technical reference.
- Fuel Requirements Technical Reference (410002) – The fuel requirements document provides detailed information about fuel characteristics required for proper operation of any Capstone microturbine.
- CRMS Technical Reference Maintenance Edition (410014) – The service edition of the Capstone Remote Monitoring Software (CRMS) provides more detailed interaction with the C200 than the local display alone. The CRMS Maintenance Edition explains how to operate this service software.
- C200 Troubleshooting Guide (430070) – This document provides detailed descriptions of troubleshooting codes and suggested actions to resolve problems.

CHAPTER 2: PRODUCT OVERVIEW

The Capstone C200 microturbine is an adaptable, low-emission, and low maintenance power generation system. A turbine-driven high-speed generator is coupled with digital power electronics to produce high quality electrical power.

The Capstone microturbine is a versatile power generation system suitable for a wide range of applications. Capstone's proprietary design allows users to optimize energy costs while operating in parallel with an electric utility grid.

The Alternating Current (AC) electrical power output from the microturbine can be paralleled with an electric utility grid or with another generation source. The microturbine can act as a Stand Alone generator for standby, backup, or remote off-grid power. Multiple systems can be combined and controlled as a single larger power source, called a MultiPac.

The microturbine can efficiently use a wide range of approved hydrocarbon-based gaseous fuels.

The microturbine produces dry, oxygen-rich exhaust with ultra-low emissions. Utilizing both the generated electric power and the exhaust heat can provide even greater energy cost savings.

Key Mechanical Components

The key mechanical components that make up the Capstone microturbine are shown in Figure 2-1.

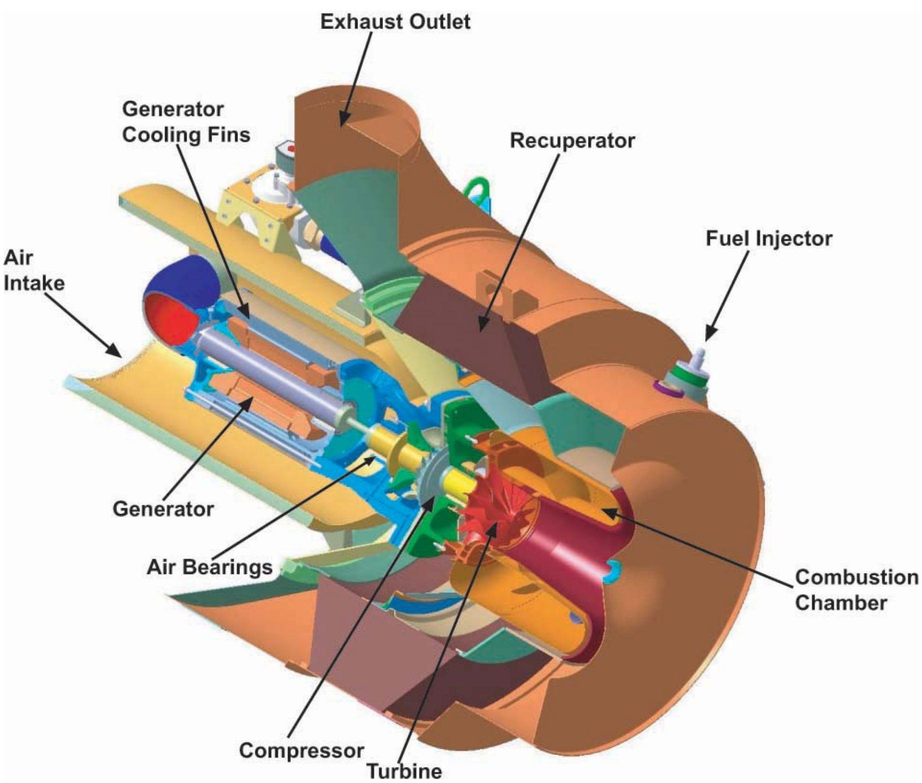


Figure 2-1. Typical Capstone C200 Turbogenerator Construction

Main Features

The main features of the Capstone microturbine are listed below:

- A state-of-the-art digital power controller with built-in protective relay functions provides two output choices:
  - Built-in synchronous AC
  - Stand Alone AC output (optional).
- Patented air bearings eliminate the need for oil or other liquid lubricants.
- Air-cooled design of the entire system (turbine and controller) eliminates the need for liquid coolants.
- The engine has only one moving part: no gears, belts, or turbine-driven accessories.
- Advanced combustion control eliminates the need for ceramics or for other costly materials or for catalytic combustion, and provides ultra-low emissions.
- The integral annular recuperator (heat exchanger) doubles electrical efficiency.
- Digital control technology facilitates advanced control and monitoring, and diagnostic capabilities, both on-board and remotely.

Air Bearings

The microturbine utilizes air foil bearings (air bearings) for high reliability, low maintenance, and safe operation. This allows fewer parts and the absence of any liquid lubrication to support the rotating group. When the microturbine is in operation, air film separates the shaft from the bearings and protects them from wear.

Emissions

The Capstone microturbine is designed to produce very clean emissions. The exhaust is clean and oxygen rich (approximately 18% O_2) with very low levels of air pollutants. Like all fuel combustion technology, the microturbine produces emissions (like nitrogen dioxide and carbon monoxide) from the fuel combustion process. The microturbine has ultra low nitrogen dioxide (NO_2) and carbon monoxide (CO) emission levels. Refer to the Capstone Emissions Technical Reference (410065) for details.

Enclosure

The microturbine standard enclosure is designed for indoor and outdoor use, and conforms to the National Electrical Manufacturers Association (NEMA) 3R requirements.

Stand Alone or Dual Mode Option

A "Dual Mode" option is available for the microturbine. This option allows operation either with or without connection to an electric grid (termed "Grid Connect" or "Stand Alone" operation respectively). This Dual Mode option includes two large battery packs used for unassisted start and for transient electrical load management. The battery packs are lead-acid type and completely sealed.

When operating in Stand Alone mode, the system can power connected loads at user-selected voltage and frequency setpoints. It can power remote facilities such as construction sites, oil fields, offshore platforms, and other locations where the electric utility grid is not available.

Distributed Generation

The microturbine produces synchronous current when connected to an electric utility grid. It allows electric utilities to expand power generation capacity in small increments, to optimize current infrastructure, and reduce or delay the need to develop, fund, and build new transmission and distribution lines. The Microturbine also allows utility consumers to offset part of their energy consumption from the grid.

Heat Recovery Module

The C200 Heat Recovery Module (HRM) accessory operates with the C200 microturbine to provide hot water heat recovery. The HRM is an exhaust economizer with integral temperature setpoint controller and exhaust diverter. The controller provides digital readout of water temperature leaving the heat exchanger, and allows the user to set the desired outlet temperature. An electrically operated exhaust gas diverter valve is actuated by the controller to maintain outlet temperature to the selected setpoint. Power for the controller and actuator can be supplied by the auxiliary electrical output of the C200.

Operational Features

Operational features of the Capstone C200 microturbine are summarized in the following:

- Peak Shaving – The microturbine can augment utility supply during peak load periods, thus increasing power reliability and reducing or eliminating peak demand charges.
- Combined Peak Shaving and Standby – The microturbine can be used for both Grid Connect power and Stand Alone power for protected loads. With the Dual Mode System Controller (DMSC) accessory, the microturbine can be programmed to switch automatically upon loss/restoration of electric utility grid power. The microturbine, with its low emissions, low maintenance requirements, and high reliability is well suited for combination peak-shaving and standby power applications.

- MultiPac Power – C200 microturbines can be installed in groups of up to 20 units using a standard Capstone MultiPac communications cable. This MultiPac capability enables connected microturbines to operate as a single power generation source. A MultiPac configuration features a single control point and synchronous voltage and frequency output for all units. Individual microturbines share power, current, and load on both a dynamic and steady state basis. An optional Capstone Advanced Power Server (APS) can be used to manage the power distribution for more than 20 microturbines.
- Resource Recovery – Capstone microturbine models are available that use methane-based oilfield flare casing gas or low-energy landfill/digester gas as fuel sources. C200 models are available that can accept Sour Gas with up to 5000 ppmV Hydrogen Sulfide (H_2S) content. This application helps reduce pollution and provides economical power for on-site use as a by-product.
- Thermal Heat Recovery – The oxygen-rich exhaust from the microturbine can also be used for direct heat or as an air pre-heater for downstream burners. The optional C200 HRM allows commercial businesses to offset or replace local thermal loads such as domestic hot water, space heating, pool heating, and industrial hot water. In addition, the oxygen-rich exhaust together with ultra-low emissions makes the direct exhaust applicable for some food processing and greenhouse uses, such as heating, cooling (by absorption), dehumidifying, baking, or drying.
- OEM Applications – The microturbine core technology can be integrated into a wide variety of products and systems. Uninterruptible power supplies, all-in-one combined heat and power systems, and welding machines are just a few examples of OEM applications.

Output Measurements

The measurements presented in this document are mostly in metric units (with U.S. standard units in parentheses). Refer to the sections below for more data.

ISO Conditions

Combustion turbine powered devices (including the Capstone microturbine) are typically rated at 15 °C (59 °F) at sea level, or 1 atmosphere (1 atm) which is 760 mm Hg (14.696 psia) and identified as International Standardization Organization (ISO) conditions. For a complete definition of ISO testing conditions, refer to ISO 3977-2.

Pressure

Pressure figures assume gauge pressure, or 1 standard atmosphere (1 atm) 760 mm Hg (14.696 psia) less than absolute pressure, unless otherwise indicated.

Volume

Fuel gas and exhaust gas volumetric measurements are given in normalized cubic meters (m^3), defined at 0 °C (32 °F), and standard cubic feet (scf), defined at 15.6 °C (60 °F). Both volumes are defined at 1 atm (760 mm Hg, 14.696 psia).

Heating Values

Heat contents and heat rates will be found in either Lower Heating Value (LHV) (dry) or Higher Heating Value (HHV), depending upon the application. Capstone calculates heating values at 1 atmosphere (atm) and 15.6 °C (60 °F), according to ASTM D3588.

Microturbine Performance

The microturbine electrical output capability is reduced when operating in higher ambient temperatures or elevations, and by intake or exhaust restrictions. Refer to Chapter 7: Performance in this document for details.

Grid Connect Output

The microturbine electrical output in Grid Connect mode is 3-phase, 400 to 480 VAC and 50 to 60 Hz (both voltage and frequency are determined by the electric utility grid).

Allowable connection types include a 4-wire wye either solidly grounded or grounded through a resistor. For neutral ground resistor requirements refer to CHAPTER 8: Electrical Ratings - Grid Connect.

Stand Alone Output

When equipped with the Stand Alone option, the electrical output is user-adjustable from 150 to 480 VAC and from 45 to 60 Hz.

The output power need not be balanced. Loads can be connected 3-phases or single phase and phase-to-phase or phase-to-neutral, so long as the current limits of each phase are respected. A Ramp Start feature can assist in starting single/individual loads with large in-rush currents. Refer to CHAPTER 8: Electrical Ratings - Stand Alone in this document for more details.

Power Quality

The microturbine output conforms to IEEE 519-1992, IEEE Recommended Practices, and Requirements for Harmonic Control in Electrical Power Systems. Refer to CHAPTER 8: Electrical Ratings in this document for more details.

Heat Output

The recuperated microturbine can produce up to 1,420,000 kJ (1,350,000 Btu) per hour of clean, usable exhaust heat in the range of 232 to 310 °C (450 to 590 °F). The microturbine exhaust stream is 305 mm (12 in) in diameter, flowing up to 62 normal m^3 (2300 scf) per minute. Refer to CHAPTER 7: Performance in this document for more details.

Maintenance

The C200 microturbine system requires little maintenance due to its use of air bearings. The use of air bearings, coupled with the fact that the microturbine system does not incorporate a mechanical transmission, means that no lubricants or coolants need to be periodically replaced or disposed of. Refer to Chapter 11: Maintenance in this document for details, including expected battery life for Stand Alone systems.

Certifications, Permits, and Codes

The Capstone C200 microturbine is designed and manufactured in accordance with a variety of national and international standards, including Underwriters Laboratories (UL), the American National Standards Institute (ANSI), European Norms (EN), the Institute of Electrical and Electronic Engineers (IEEE), and the California Air Resources Board (CARB). For detailed information on the requirements of each authority having jurisdiction and how the Capstone microturbine meets those requirements, contact your Capstone Authorized Service Provider for assistance and the latest Capstone microturbine Compliance List.

CHAPTER 3: SYSTEM DESCRIPTION

Overview

The C200 microturbine System is a gas turbine generator that provides electric power and clean process heat. The C200 is an integrated product that uses advanced solid-state power electronics to produce utility grade 3-phase electrical power at 400/480 VAC and 50/60 Hz.

The integrated microelectronic controllers synchronize with the electric utility and provide utility protection, thereby eliminating the need for additional third party protective equipment.

The C200 is based on the same proven architectural concepts as the Capstone Model C65 microturbine. The C200 has an extremely high power density due to the high rotational speed of its permanent magnet generator. The C200 has high electrical efficiencies for a turbine because it incorporates an air to air heat exchanger, called a recuperator. By recovering exhaust waste heat, and using it to pre-heat combustion air, the recuperator reduces the amount of fuel consumed by a factor of two.

Major C200 Functional Elements

The major functional elements that make up the Capstone C200 microturbine system are shown in Figure 3-1.

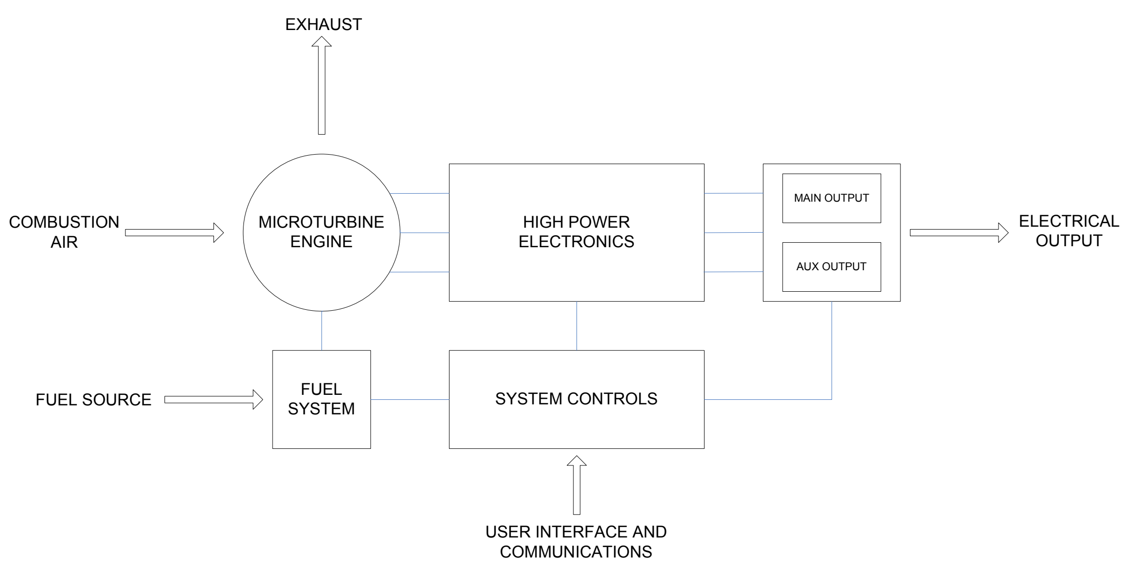


Figure 3-1. Major C200 Functional Elements

Microturbine Engine (or Turbogenerator)

The microturbine engine is a combustion turbine that includes a compressor, combustor, turbine, generator, and a recuperator. The rotating components are mounted on a single shaft supported by patented air bearings and spin at a maximum speed of 60,000 RPM. The permanent magnet generator is cooled by the airflow into the microturbine. The output of the generator is variable voltage, variable frequency AC. The generator is used as a motor during start-up and cooldown cycles.

Fuel System

The microturbine can efficiently use a wide range of approved hydrocarbon-based gaseous fuels, depending on the model. The microturbine includes an integral fuel delivery and control system. The standard system is designed for pressurized hydrocarbon-based gaseous fuels. Other models are available for low-pressure gaseous fuels, gaseous fuels with lower heat content, gaseous fuels with corrosive components, and biogas (landfill and digester gas) fuels. Contact your Capstone Authorized Service Provider for data on approved fuels and performance specifications.

Power Electronics

Digital power electronics control and condition the microturbine electrical output. The digital power electronics change the variable frequency AC power from the generator to DC voltage, and then to constant frequency AC voltage.

During start-up, the digital power electronics operate as a variable frequency drive, and motor the generator until the microturbine has reached ignition and power is available from the microturbine. The digital power electronics again operate as a drive during cooldown to remove heat stored in the recuperator and within the microturbine engine in order to protect the system components.

Electrical Output

The C200 microturbine provides two electrical output connections:

- The main 3-phase AC power, which can provide up to 200KW
- An auxiliary 3-phase AC output, which can provide up to 10 kVA prior to the main power becoming available.

The auxiliary power can be used for short periods of time to drive smaller three phase AC loads from the optional battery system, such as an external fuel gas booster or heat recovery system water pump.

System Controls

The digital system controls govern the operation of the microturbine Generator and all electronic subsystems, including the high power electronics, the fuel system and electrical output module.

User Interface and Communications

The microturbine end users have several methods at their disposal to configure and operate the C200 microturbine system. The system comes equipped with a wide array of digital input and output connections to facilitate full integration into any Building Management System, Supervisory Control and Data Acquisition (SCADA) or Programmable Logic Controller (PLC) based application. Options are available to communicate with the microturbine via RS-232 serial communications, telephone modem, or internet. The microturbine can be monitored, as well as commanded with optional interfaces. Fault codes are accessible over the various communication links to assist with remote troubleshooting.

Exhaust

Clean hot exhaust air can be used for process heating or cooling and can increase the overall efficiency of the system. This exhaust may be directed to an optional air to water heat exchanger. Alternately, the exhaust may be directed to customer provided devices, such as absorption chillers, which can generate cold water from the hot exhaust.

Control System Components

The C200 microturbine is controlled by multiple proprietary digital controllers that work in unison to deliver the required power for the user. The system runs in one of two primary operating modes. The first mode is called Grid Connect where the system will generate power at the level requested by the user and deliver it to the existing, active power grid in the user's facility. The other mode of operation is Stand Alone. In Stand Alone, the microturbine is the sole source of electrical generation and generates the power necessary to support whatever load is connected to it as long as the load is below the maximum capacity of the generator.

There are five primary independent digital controllers in the microturbine systems that are responsible for their own specific task. These are:

- Load Controller, located in the Load Control Module
- Generator Controller, located in the Generator Control Module
- Engine Controller, located in the Fuel Metering Module
- Two identical Battery Controllers, one in each Battery Control Module
- System Controller, located in the System Control Module.

Connecting these controllers are a low voltage DC bus and a communication bus. Power and communication between these controllers flow over these bus connections as can be seen in Figure 3-2.

Each of the major components has a Personality Module (PM) embedded in it. The PM is an Electrically Erasable Programmable Read Only Memory (EEPROM) device which is used to store operational parameters and user settings for each of these components. This allows the main operating software to identify, and adjust for the operation of, various machine configurations. These PMs can be read and programmed through the CRMS Software. Refer to the CRMS Technical Reference, Maintenance Edition (410014) for PM upload and download instructions.

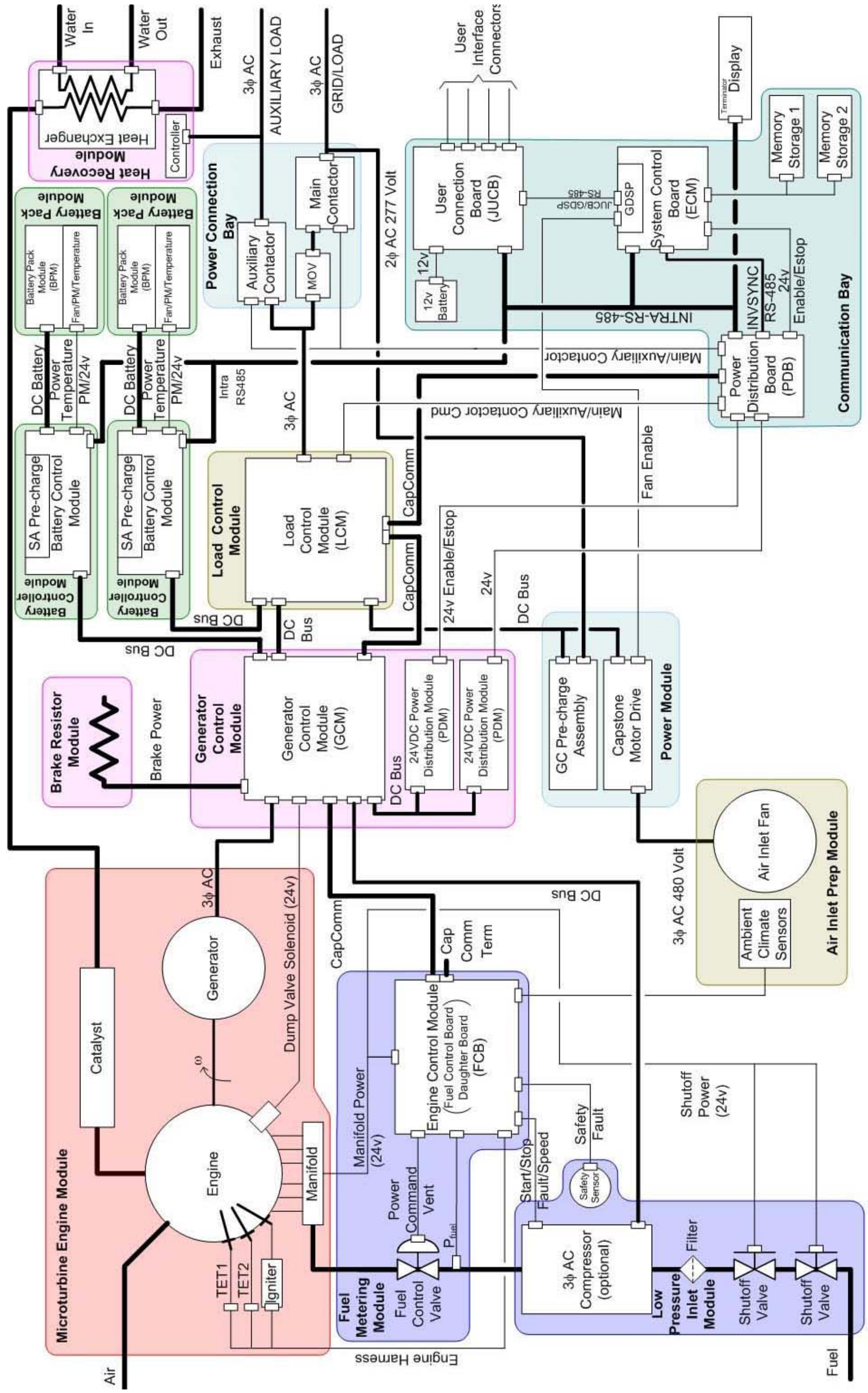


Figure 3-2. Major Microturbine System Components

Load Controller

The C200 Load Controller is one of the primary digital controllers and is responsible for converting power from the high power DC bus to the customer's desired AC output voltage and frequency or in the reverse direction in order to start the engine. In the case of a Grid Connect system, the Load Controller automatically matches the existing voltage and frequency of the customer's grid.

Generator Controller

The C200 Generator Controller is dedicated to fully active speed control of the permanent magnet AC generator/motor. This controller provides high frequency AC power to initially spin the engine up to the desired starting speed by flowing power from the DC bus. Once the system lights off, it controls the speed of the engine ensuring that the system remains at the speed to which it was commanded in order to generate power. Then Generator Controller then transfers that power to the DC bus. This controller also has control of the safety valve that opens and dumps compressed air overboard in the event of a loss of speed control, and a brake resistor that can be used to control excess power on the DC bus.

Engine Controller

The C200 Engine Controller is responsible for regulating fuel, the igniter, and all engine sensors. It initiates the lighting sequence of the engine and then controls the operating temperature with the flow of fuel once ignition is detected. Controlling of the fuel also includes control of the flow to the six individual fuel injectors.

Battery Controllers

The C200 has two identical Battery Controllers that convert the battery DC bus voltage from two large DC batteries to the system high power DC bus voltage. These controllers are responsible for the sourcing or sinking of power as necessary to regulate the DC bus. These controllers are only found on Stand Alone systems as the inverter regulates the DC bus on grid connect systems using grid power. During a start on a Stand Alone system, the Battery Controllers are responsible for turning on and charging the system's high power DC bus. They also have built in battery health and monitoring software to manage the charge of the system's batteries.

System Controller

The C200 System Controller is responsible for management of the entire microturbine operation and the interfacing to the outside world. It commands the individual controllers to the correct operation states and operation settings at the proper time to regulate the entire system. It takes manual commands from the user through the Display Panel, digital commands over the RS-232 communication bus (using the Capstone Remote Monitoring System (CRMS) software) from a computer or from a MODBUS converter, MultiPac communication from another turbine, Advanced Power Server, or direct discrete analog or digital inputs. This controller logs all system faults and records data prior to, during, and after all logged faults for the last 20 faults on record. As an additional safety feature, it has control of all low voltage DC power to the fuel valves and will disable the fuel system, independent of the Engine Controller, in the event of a fault.

Operational States

Figure 3-3 and Figure 3-4 show the C200s operational states and all possible transitions between states. The transitions and active states can be different between Grid Connect and Stand Alone operation. The fault logic will transition directly out of any state into the Disable, Warmdown, or Fault state depending upon the severity of the fault. If the user initiates a download of new software, then the system transitions to the Software Download state and remains there until the system is restarted to ensure that the power is cycled after downloading new software. This cycle of power is also required if the system ever faults out and ends up in the Disable state.

Power Up

The Start-Up sequence differs for Grid Connect and Stand Alone modes:

- For Grid Connect, the user needs to provide power from the Grid Connection to the main electrical terminal connections on the microturbine. Once power is applied, the system's DC bus precharge circuit powers up the main DC power bus that supplies power to the 24 VDC power supplies.

These power supplies provide power throughout the system to all the individual digital controllers putting the system into the Power Up control state on the main controller.

- For Stand Alone, the user presses the Battery Wakeup button on the Display Panel or closes the external battery wakeup circuit momentarily. This circuit applies the 12 V power from the small battery in the user connection bay to the battery controllers, latching a contact that enables the precharge circuit in the battery controllers to activate the battery's main controller. The battery's main controller then energizes the system's primary DC bus using power from the main batteries. The system then starts up the same way as the Grid Connect system.

While in the Power Up state, the System Controller goes through all of its system checks, checks that all other controllers have also passed their system checks, and checks that it has the correct hardware connected for this type of system. It then checks the hardware inputs to determine if it is configured to be a Grid Connect, Stand Alone, or Dual Mode system. If there are errors during this process, then the system transitions to the Invalid state. If the jumpers and hardware are correct, the system transitions to the Stand By state.

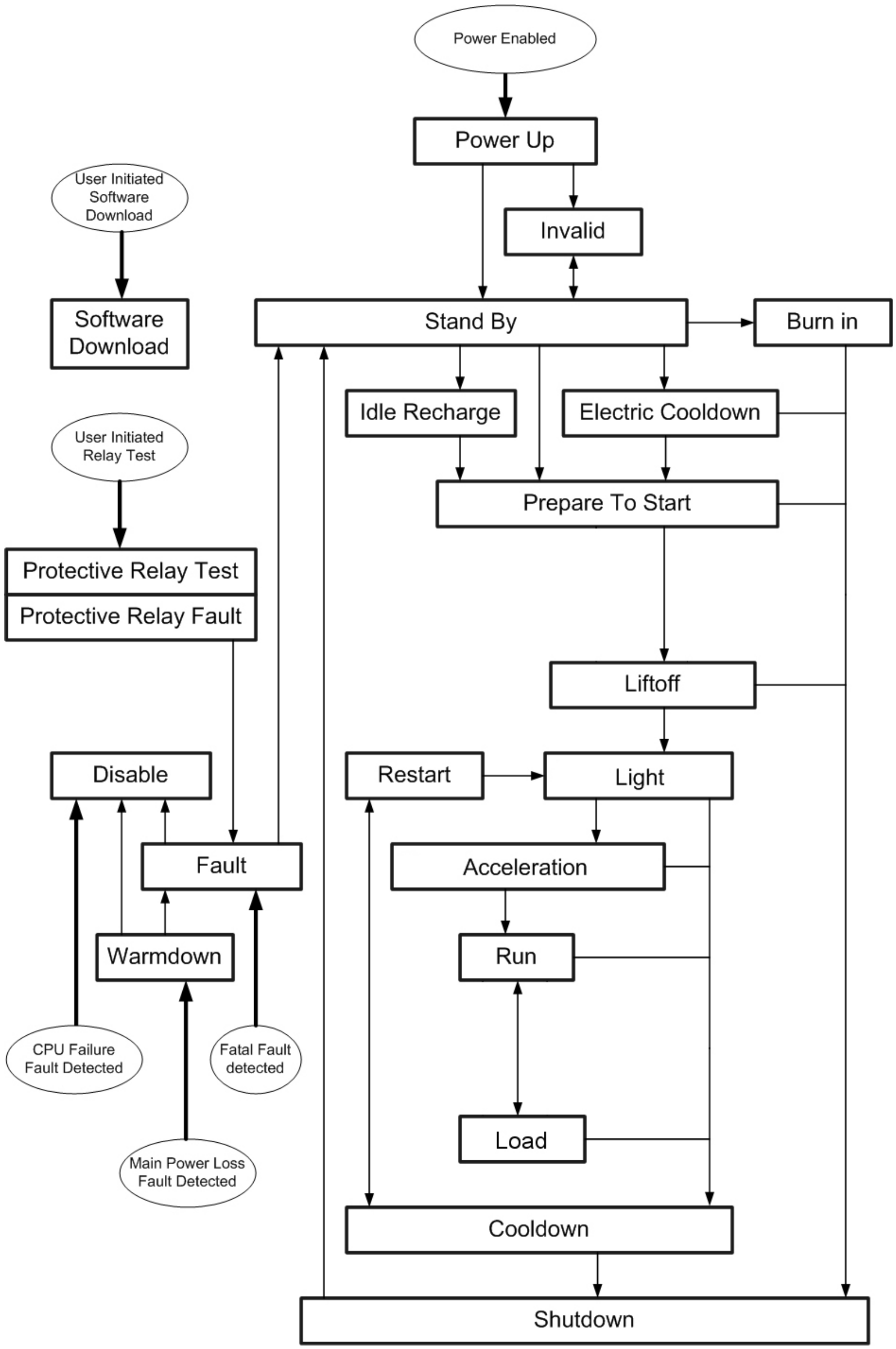


Figure 3-3. System Operational States – Grid Connect

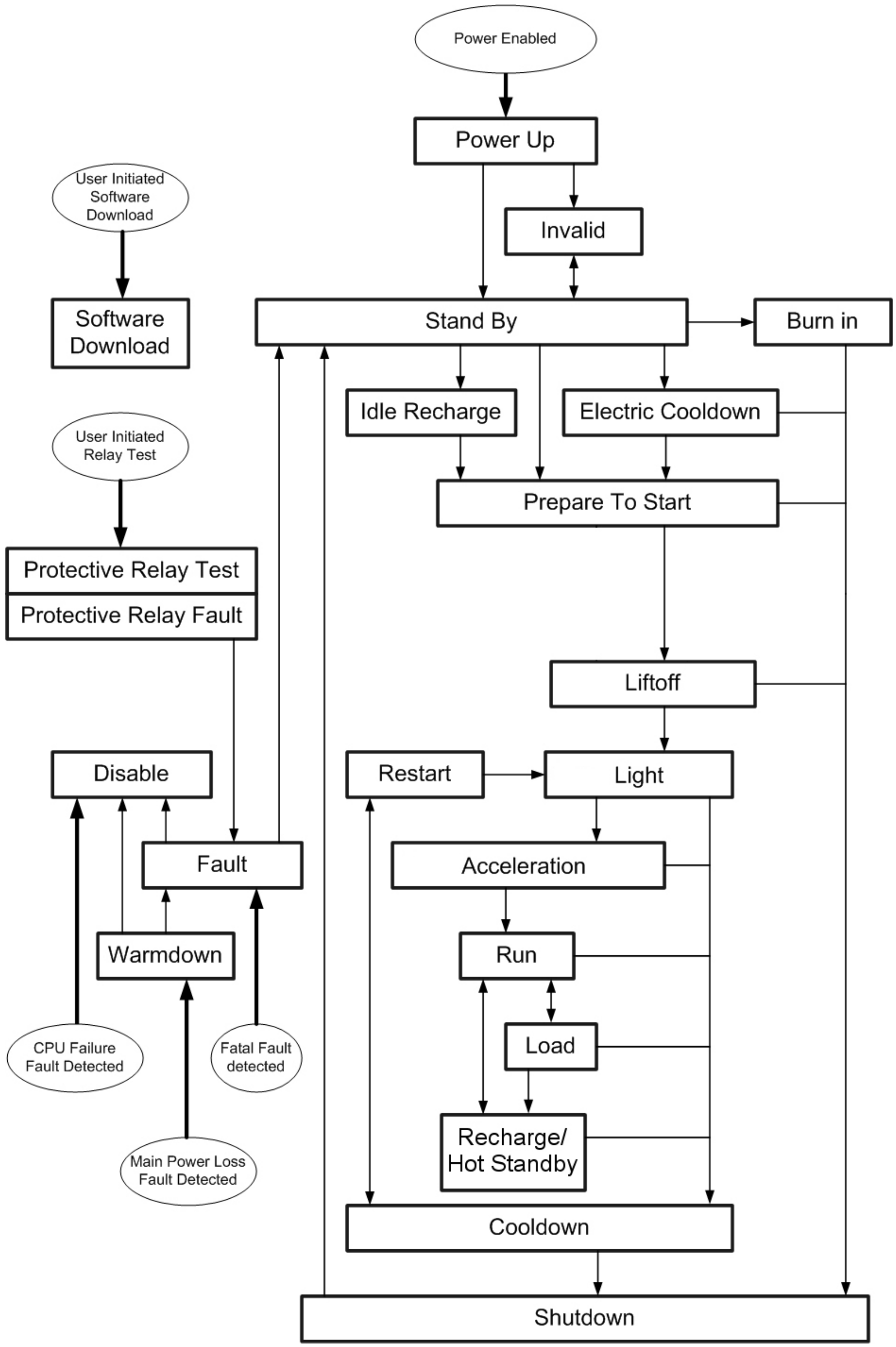


Figure 3-4. System Operational States – Stand Alone

Invalid

This is the state the system transitions to when the software or hardware does not match or if there have not been any jumpers installed to identify the mode in which to run. New systems are delivered in this manner and will end up in this state upon initialization.

Stand By

This is the primary state for the microturbine after power up or anytime the unit is on but not issued a Start command. For Grid Connect, the system will stay in this state as long as grid power is applied to the terminals. For Stand Alone, the system has a timer that will turn off the power and wait for a battery wake-up command to start back up after the timer expires. This timer is user adjustable.

Burn In

This state is used to burn in new power electronics during production build.

Idle Recharge

This state is available for Dual Mode or Standby systems that have batteries but do not run in Stand Alone mode except in the very rare instances of a power outage. The user can command the system to this state to charge the main batteries. The microturbine uses power from the grid to perform a complete charge of the batteries in order to maintain their health.

Cooldown

This state is transitioned to if the power electronics are too hot and need to be cooled down prior to starting the system.

Prepare to Start

This state prepares the system to run at power. It sets the proper operating modes and then enables the Load Controller, Generator Controller, and Battery Controllers (if present). Once these are functioning correctly, the primary cooling fan is powered.

Liftoff

In this state, the Generator Controller is commanded to bring the engine quickly up to its start speed. Once this speed is reached successfully, the Generator Controller is put in speed control mode and the system transitions to the next state in the sequence.

Light

This is the state where the combustion system is ignited. The System Controller commands the Engine Controller to initiate the light sequence. The Engine Controller enables the igniter and ramps the flow of fuel at the proper rate for the customer's fuel type until ignition is detected. Once the system controller detects the lightoff, the System Controller places the Engine Controller in closed loop temperature control and transitions to the next state.

Acceleration

The system controller waits in this state until the Generator Controller has transitioned the engine speed up to the minimum engine idle speed before transitioning to the next state.

Run

This is the state the system stays in until the engine is fully warmed up and the load command is set by the user. Once both of these conditions are met, the System Controller transitions to the Load state.

Load

In this state, power is generated out of the system. In Grid Connect, the system will meet the commanded demand of the user. In Stand Alone, the system will support the entire load connected to the microturbine up to the limit of the microturbine output.

Recharge (Hot Standby)

This state is only active for Stand Alone systems. In Stand Alone, it is critical to make sure the batteries are charged prior to shutting down. Therefore, the System Controller disables the main output power, but continues to produce power with the engine thus allowing the battery controllers to fully charge the main system batteries. The time for this charge will vary with the existing health of the batteries at the time of shutdown. Once the batteries are fully charged, the System Controller continues to the next state. The system is also available to transition back to Load state, such as when commanded to return to Grid Connect mode after a utility outage. This state is also referred to as Hot Standby.

Cooldown

In this state, the System Controller turns off the Engine Controller which turns off the fuel to the engine. Once the fuel is off, the System Controller monitors the engine temperature until it has dropped enough to stop the engine. It then transitions to the next state.

Restart

This state exists to allow the user to restart the microturbine without completely shutting down first. The System Controller commands the system back to the lightoff speed and then transitions back to the Open Loop Light state.

Shutdown

In this state, the System Controller commands the Generator Controller to run the engine back down to the Liftoff speed and then quickly to zero speed. Once the speed of the engine is confirmed to be at zero, the System Controller disables the Generator Controller, the Load Controller, and the Battery Controllers (if the system is in Stand Alone mode).

Software Download

This state ensures that the system is put in the proper configuration to load new software. The system automatically enters into this state upon starting a software upload through the CRMS Software. Once the software load is complete, the user must cycle power in order to exit this state.

Protective Relay Test and Protective Relay Fault

This state allows a test of the protective relay functionality. If the proper fault is detected, the System Controller transitions to the Fault state.

Fault

This is the state that all active operating states (except the Standby state) transition to if a shutdown level fault is detected. Once everything is turned off, the system will clear the fault and transition back to Standby if the fault can be reset.

Warmdown

This is the state that all active operating states transition to if a fault occurs that disables the primary source of start power. In Grid Connect mode, the primary source of start power is the Load Controller while for Stand Alone mode it is the Battery Controllers.

Disable

This is the final state for all severe faults and can be transitioned to from any state. Once you enter this state, power in the entire system is shut down and if in Stand Alone mode, the system goes to sleep. If you are in Grid Connect mode and the precharge circuitry is still working, the controller and display could possibly stay on depending on the severity level and type of fault.

Power Electronics Components

The Capstone C200 microturbine utilizes advanced solid state high power electronics to provide high quality electrical power. In Grid Connect mode, the microturbine supplies power as a current source to an energized electrical grid. In Stand Alone mode, the microturbine supplies power as a grid-isolated voltage source.

Figure 3-5 shows the major components of the high power electronics.

- Generator Control Module
- Load Control Module
- Battery Control Modules (Stand Alone configuration only)
- Battery Packs (Stand Alone configuration only)
- Precharge Transformer
- Main Output Contactor
- Auxiliary Output Contactor
- Brake Resistors

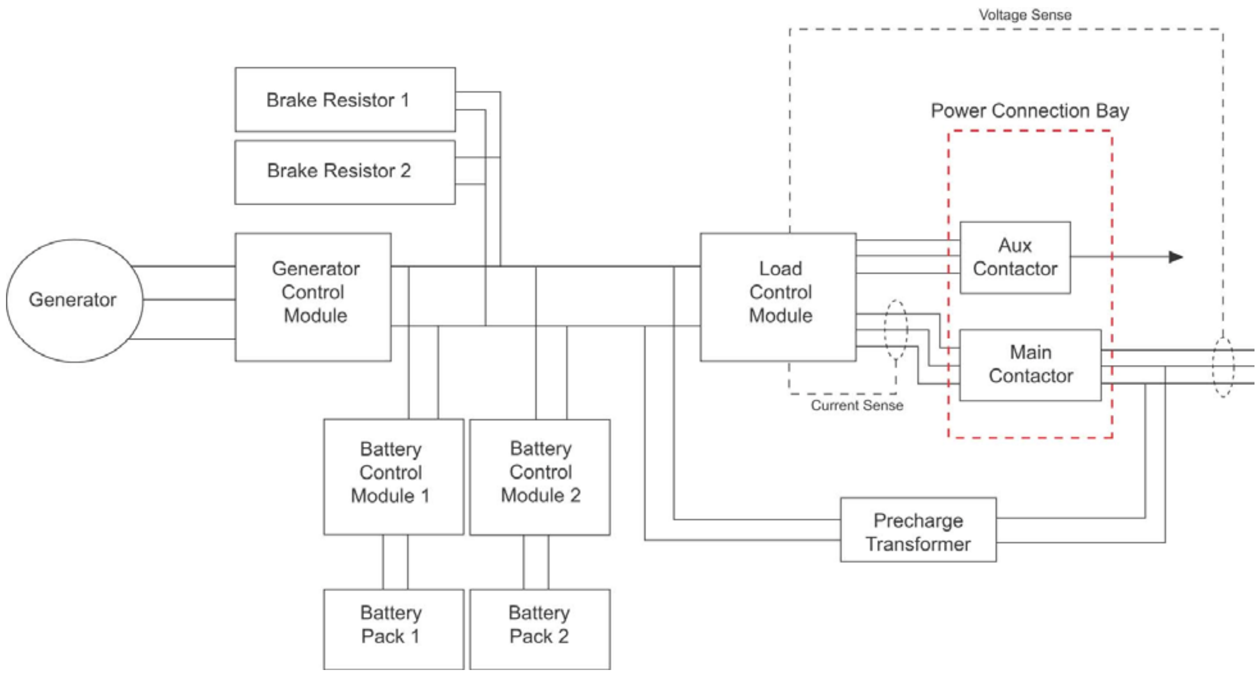


Figure 3-5. High Power Electronics Components

Generator Control Module

The generator control module converts the variable frequency, variable voltage output from the microturbine generator into a high voltage DC bus.

Load Control Module

The load control module actively switches the output of the DC bus into synchronized 3-phase voltage and frequency.

Battery Control Modules

The battery control modules, included with Stand Alone or Dual Mode systems, convert the stabilized high DC voltage to a lower DC voltage as that of the battery packs.

Battery Packs

The Battery packs, included with Stand Alone (or Dual Mode) systems, provide the power electronics with stored energy for black starting and load transients.

Precharge Transformer

The precharge circuit serves in Grid Connect applications to activate the DC bus using grid power in order to initialize the power electronics. The precharge circuit limits the in-rush current to the DC bus during power up.

Main Output Contactor

The main output contactor is used to initiate and stop export of the system's main electrical power output, and is located in the Power Connection Bay.

Auxiliary Output Contactor

An auxiliary output contactor provides a small amount of 3-phase AC power to selected loads for a short time prior to the main output contactor closing, and is located in the Power Connection Bay.

Brake Resistors

To prevent an overvoltage condition from occurring on the DC bus, a brake resistor is connected across to the DC bus. These resistors are activated when the DC bus exceeds a predetermined voltage setpoint which can occur as a result of rapid load shedding or an emergency stop.

CHAPTER 4: OPERATING MODES

This section describes the Grid Connect and Stand Alone operating modes, including transitions between these operating modes, MultiPac operation, and Dispatch modes.

Grid Connect

Introduction

Grid Connect mode allows the microturbine to be connected in parallel with an electric utility. When a utility grid disturbance occurs, the protective relay functions integrated into the C200 microturbine will automatically shut down the system. The C200 can restart automatically to resume supplying electricity to connected loads once grid power returns to normal. In Grid Connect mode, the microturbine is a current source only - the microturbine synchronizes to the electric utility for both voltage and frequency reference. The microturbine can be used to provide base load power or shave peak power based on loads or user commands.

Features

The microturbine in Grid Connect operation allows electric utilities to expand generating capacity in small increments. This optimizes current infrastructure and reduces the need to upgrade specific site capacity and lowers overall costs. Grid Connect capabilities also include programmable peak shaving functions, which automatically configure the microturbine to operate on a timed schedule or to follow local loads, thereby reducing peak demand charges. These special features are described as Time of Use and Load Following dispatch modes later in this chapter. Time of Use supplies variable power levels at selected times to meet user load demand. Load Following tracks local electrical loads to supply power on an as-needed basis. An additional feature, Reverse Power Flow Protection, prevents the microturbine system from backfeeding the grid. Implementation of Load Following mode and Reverse Power Flow Protection requires installation of an external power meter and/or a timer or switch. The external power meter provides information to the microturbine on power flow at a point between the microturbine and the grid power supply.

Power Specifications

The power output in Grid Connect mode is three phase 400 to 480 V, 50/60 Hz. The microturbine automatically synchronizes with the grid, and will operate properly with either clockwise or counter clockwise phase rotation. For complete performance ratings, refer to Chapter 7: Performance and Chapter 8: Electrical Ratings in this document. For discussion of the protective relay functionality, refer to Chapter 9: Protective Relay Functions. For discussion of electrical interconnections, refer to Chapter 10: Communications and Chapter 12: Installation in this document.

Configuring Grid Connect Mode

The C200 microturbine must be told what mode to operate in. This requires both hardwire connections in the User Connection Bay, and software commands from the front panel display or through one of the serial communications ports using a PC with CRMS. To operate in Grid Connect mode, the following needs to be done:

- Set the System "Power Connect" mode to "Grid Connect" using the Display or using a PC with CRMS.
- Provide external control connections to the Grid Connect enable input in the User Connection Bay. Refer to Dual Mode below for a discussion of how to switch between Grid Connect and Stand Alone modes. Refer to Chapter 10: Communications in this document for details on pin connections.

In addition to this Grid Connect mode setup, means to start and stop the system must be configured. The sections below provide additional functions to be considered for setting up dispatch modes. The Chapter 10: Communications provides description of other input and output options, including Emergency Stop and fault inputs.

Note that setting Auto Restart to ENABLE impacts both Grid Connect and Stand Alone operating modes. Separate adjustable timers can be used to set different restart time delays for Grid Connect and Stand Alone modes. These timers are only adjustable using CRMS.

The system power demand will also need to be set. Refer to the C200 Users Manual (400008) and CRMS Technical Reference User's Edition (410013) for configuring all these settings.

Auto Restart

A system operating in Grid Connect can be set to automatically attempt a restart after low-severity incident-driven shutdowns. If Auto Restart is ON, the system will attempt to restart after a shutdown due to any fault condition that is severity level 3 or less. This feature may be enabled with any of the dispatch modes described below. Capstone recommends enabling Auto Restart to increase system availability, deliver faster power output and reduce wear on the bearings.

If the Auto Restart feature is enabled, the system stores the ON command through a loss of utility power. However, the microturbine must be explicitly commanded ON for the Auto Restart operation to function; for example the system will not automatically restart and reconnect to the grid if the Time of Use mode is not telling the system to be ON at that point. Operator intervention is required to manually restart the system if a utility fault condition occurs and the related protective relay function shuts the microturbine down.

The Auto Restart feature is available in both the Grid Connect and Stand Alone operating modes. However, each mode has a separate user settable delay timer that is adjustable between zero and 60 minutes.

Grid Connect Operation

Once the system has been properly wired to the utility grid and any external control wiring has been established, a Capstone Authorized Service Provider is required to complete the commissioning procedure and set protective relay settings. The end user can then refer to the C200 User Manual (400008) for proper operation and maintenance of the system.

Stand Alone

Introduction

This section presents information on operating the C200 microturbine in Stand Alone mode. Stand Alone mode allows power generation at locations where there is either no electric utility service or where backup power is desired when the electric utility is unavailable. For Stand Alone operation, the voltage and frequency of the microturbine are set to meet load requirements. The microturbine behaves as a voltage source that always follows the power requirements of the load, (i.e., the output power is determined by the actual current draw demanded by the connected loads).

The microturbine in Stand Alone mode utilizes an on-board battery storage system to power connected loads when no electric grid utility is available. The battery provides energy for starting the microturbine. During operation, the battery also provides energy for supporting power draw while the microturbine increases speed to provide the necessary power. In addition, it serves as a buffer to absorb energy during a loss of load while the microturbine decelerates to produce less power. During microturbine shutdown, the battery may be placed in sleep mode to minimize drain and preserve battery charge. Management of the battery and its state-of-charge is automatic during microturbine operation.

Features

The normal Stand Alone mode of operation is for the microturbine to pick up the connected load at its set voltage and frequency once the microturbine has been started. Stand Alone capabilities also include a Soft Start function, which allows the microturbine to begin exporting power at less than nominal voltage and frequency, and then linearly increases voltage and frequency to nominal levels over a period of time. This Soft Start feature can assist in starting loads with large in-rush currents, such as a single large dedicated motor. To meet output power requirements automatically, the system can be configured in Auto Load mode. Auto Load ensures that the microturbine closes the main output contactor to immediately produce the required output power once minimum engine load speed and battery state of charge are reached.

The C200 microturbine includes integrated protective relay functions to check output voltage and frequency, and will shut down if values fall outside of preset limits. The system will also automatically shut down, and will not pick up load, if it senses utility voltage. If the connected loads demand more power than the engine is able to produce, the microturbine will take additional power from its battery storage system to make up the difference until the battery state of charge drops below 60 percent.

Power Specifications

The full-load power output in Stand Alone mode is three phase 150 to 480 V, 50/60 Hz. The microturbine provides output in L1, L2, L3 counter clockwise phase rotation. For complete performance ratings, refer to Chapter 7: Performance and Chapter 8: Electrical Ratings in this document. For discussion of the protective relay functionality, refer to Chapter 9: Protective Relay Functions. For discussion of electrical interconnections, refer to Chapter 10: Communications and Chapter 12: Installation in this document.

Configuring Stand Alone Mode

The C200 microturbine must be told what mode to operate in. This requires both hard wired connections in the User Connection Bay, and software commands from the front panel display or through one of the serial communications ports using a PC with CRMS. To operate in Stand Alone mode, the following needs to be done:

- Set the System "Power Connect" mode to "Stand Alone" using the Display or using a PC with CRMS.
- Provide external control connections to the Stand Alone enable input in the User Connection Bay. Refer to Dual Mode below for a discussion of how to switch between Grid Connect and Stand Alone modes. Refer to Chapter 10: Communications in this document for details on pin connections.

In addition to this Stand Alone mode setup, a means to start and stop the system must be configured. The sections below provide additional functions to be considered for setting up soft start and dispatch modes. The Communications chapter provides description of other input and output options, including Emergency Stop and fault inputs.

The system voltage and frequency will also need to be set. Refer to the C200 Users Manual (400008) and CRMS Technical Reference User's Edition (410013) for configuring all these settings.

Auto Restart

The C200 microturbine system can normally be restarted after a shutdown, while the battery recharges, or during the Cooldown period before the speed of the microturbine reaches zero. This allows for faster power output and reduced bearing wear. If Auto Restart is ON, the system will attempt to restart after low-severity incident-driven shutdowns. Enabling Auto Restart increases system availability and is recommended by Capstone.

Note that setting Auto Restart to ENABLE impacts both Grid Connect and Stand Alone operating modes. Separate adjustable timers can be used to set different restart time delays for Grid Connect and Stand Alone modes. These timers are only adjustable using CRMS.

Auto Load

The Auto Load option allows the user to enable the microturbine to automatically close the output contactor once the system has started and is ready to load. A "Yes" setting automatically makes power available once the microturbine is ready to generate power. A "No" setting requires the user to manually press Interlock and Enable on the C200 Display to allow the microturbine to produce power. This command can also be set through the serial port using CRMS. The Auto Load feature should be enabled to have the contactor automatically close when Auto Restart is enabled and a restart fault occurs.

Stand Alone Load Wait

The Stand Alone Load Wait function applies only to Dual Mode configured systems. This provides a timer that maintains the system in Stand Alone Load State before the transition back to Grid Connect, after the utility grid has returned to normal. The timer begins when the utility voltage and frequency are detected to be within the required operating range, and maintains the turbine in the Stand Alone load state until the time has expired. This timer is adjustable from 5 to 30 minutes.

Soft Start Functionality

Normally, the C200 provides the user-defined voltage and frequency as soon as the main output contactor is closed. However, the C200 microturbine may also be configured to begin exporting power at less than nominal voltage and frequency, and then linearly ramp to nominal values over a selected time period using the Soft Start functionality. Both voltage and frequency can be adjusted for this initial soft start function using CRMS software.

Soft Start Voltage

The Soft Start Voltage (0 to 480 V) setting is typically used to enable the microturbine to start a motor (or other loads), which cannot handle full load current immediately. This parameter differs from the Operating Voltage setting (150 to 480 V), which represents the load voltage at normal operating conditions. When the output contactor closes, the system will provide demanded current at this starting voltage and immediately begin increasing the voltage at the configured rate, up to the nominal voltage. The Start voltage can be adjusted from 0 to the normal voltage setting. Ramp Rate Volts per Second establishes the rate of voltage increase. When the output contactor closes, the system will provide demanded current at the voltage established above and immediately begin increasing the voltage at this rate. The Ramp rate can be set from 0 to 6,000 Vrms per second

Soft Start Frequency

Soft Start Frequency establishes the starting frequency. When the main output contactor closes, the system will provide demanded current at this starting frequency and immediately begin increasing the frequency up to the nominal frequency. The Start frequency can be adjusted from 0 to the normal frequency setting. Ramp Rate Hertz per Second establishes the rate of frequency increase. When the output contactor closes, the system will provide demanded current at the starting frequency and immediately begin increasing the output frequency at this rate. The Ramp rate can be set from 0 to 2,000 Hz per second.

Battery Overview

There are actually two sets of batteries that are a part of any Stand Alone microturbine system: the main batteries that provide power for starting the engine and to stabilize power output during load transients, and a small 12 VDC battery in the User Connection Bay (UCB) to provide energy to wake-up and engage the main battery system is engaged. Additional details on the main battery system are included in Chapter 5: Battery Management.

Main Battery Isolation Switch

A battery isolation switch to disable the microturbine for service or transport is located behind the lower kick panel on the C200 package. The switches on the two main battery packs must be set to ON for system operation. Refer to the C200 Users Manual (400008) for details.

UCB Battery

C200 microturbine systems utilize a separate battery located in the Communications Bay for remote system battery wake-up functionality. The +12 VDC battery is recharged automatically when the microturbine senses a low state-of-charge.

System Sleep Mode

The C200 microturbine provides a Sleep Mode to conserve battery power during prolonged periods of inactivity. This reduction in battery draw can significantly extend the microturbine battery charge. Sleep Mode inactivity time can be adjusted from 0.1 to 23.9 hours.

NOTE	If the battery isolation switch is set to ON, and the display panel is dark, the system is most likely in Sleep Mode.

Stand Alone Operation

Once the system has been properly wired to its loads and any external control wiring has been established, a Capstone Authorized Service Provider is required to complete the commissioning procedure and set protective relay settings. The end user can then refer to the C200 User Manual (400008) for proper operation and maintenance of the system.

Dual Mode

Capstone uses the term Dual Mode to describe the ability to operate in either Grid Connect or Stand Alone modes, and to be able to automatically switch between these operating modes. It is also the microturbine system designation for a version C200 which has this capability. By definition, a Dual Mode microturbine system includes the batteries and associated hardware to be able to operate in Stand Alone mode. Sometimes a Dual Mode version is used for a purely Stand Alone application (for example remote power that will never be connected to a utility grid). In this case, the Dual Mode features described here will not be used, and only the Stand Alone operation description above will apply. For many applications, however, the system is intended to operate in Grid Connect mode most of the time, and transition to a Stand Alone mode when the utility grid experiences a fault.

Configuring Dual Mode Operation

As described in the Grid Connect and Stand Alone sections above, the microturbine must be told what mode to operate in. This requires both hard wired connections in the User Connection Bay, and software commands from the front panel display or through one of the serial communications ports using a PC with CRMS. To operate in Dual Mode, the following needs to be done:

- Set the System “Power Connect” mode to “Dual Mode” using the Display or using a PC with CRMS.
- Provide external control connections to the Stand Alone enable and Grid Connect enable inputs in the User Connection Bay. Refer to Chapter 10: Communications in this document for details on pin connections.

Once the system is configured to act in Dual Mode, activating the Stand Alone or Grid Connect inputs will manually switch between Grid Connect and Stand Alone operating modes. Care

needs to be taken to avoid conflicting commands that could damage equipment. Capstone offers a Dual Mode System Controller accessory which provides the necessary wiring and logic to sense utility grid problems and automatically switch between these two operating modes.

CAUTION	The microturbine can only provide power in L1, L2, L3 counter clockwise phase rotation in Stand Alone mode. Therefore, proper phase wiring must be respected relative to the utility grid voltage. Connections L2 and L3 to the microturbine may need to be swapped to achieve a consistent phase rotation when switching between utility voltage in Grid Connect mode and microturbine voltage in Stand Alone mode to avoid damage to loads that are sensitive to phase rotation.

Fast Transfer

The C200 is able to transition from Grid Connect to Stand Alone mode in less than 10 seconds. The microturbine is not able to reconnect to a utility grid without first sensing voltage stability for at least 5 minutes (refer to Grid Connect above). However, protected loads can be quickly transitioned back to a utility source by first stopping microturbine power output in Stand Alone mode, and then reconnecting the protected loads back to the utility. The microturbine can then continue to operate in a Hot Standby mode (producing no load power but recharging its batteries) until it senses the utility is stable and then reconnecting automatically in Grid Connect mode.

The Dual Mode System Controller Technical Reference (410071) provides details about the transitions and timing for fast transfer.

MultiPac

This section provides technical information for operating the Capstone Model C200 microturbine in a collective arrangement known as a MultiPac. In a MultiPac, microturbines can be installed in groups of up to 20 units (more with the optional Capstone Advanced Power Server) to operate as a single power generation source. Refer to the Capstone Advanced Power Server Technical Reference (480023) for details utilizing an Advanced Power Server in MultiPac installations.

MultiPac operation features synchronous voltage and frequency for all microturbines in the group. Individual microturbines share power and load on both a dynamic and steady state basis. A single physical and logical control point, designated as the “Master”, directs signal and command information to all other turbines. Any individual turbine in the group or the Advanced Power Server may be designated as the Master.

MultiPac can be operated in either of the operating modes described above: Stand Alone or Grid Connect. In each mode, individual microturbines share power, current and load on both a dynamic and steady state basis, and generate current to meet the required load demand. Dual Mode operation requires purchase of a Capstone Dual Mode System Controller.

An illustrative interconnection diagram is presented in Figure 4-1.

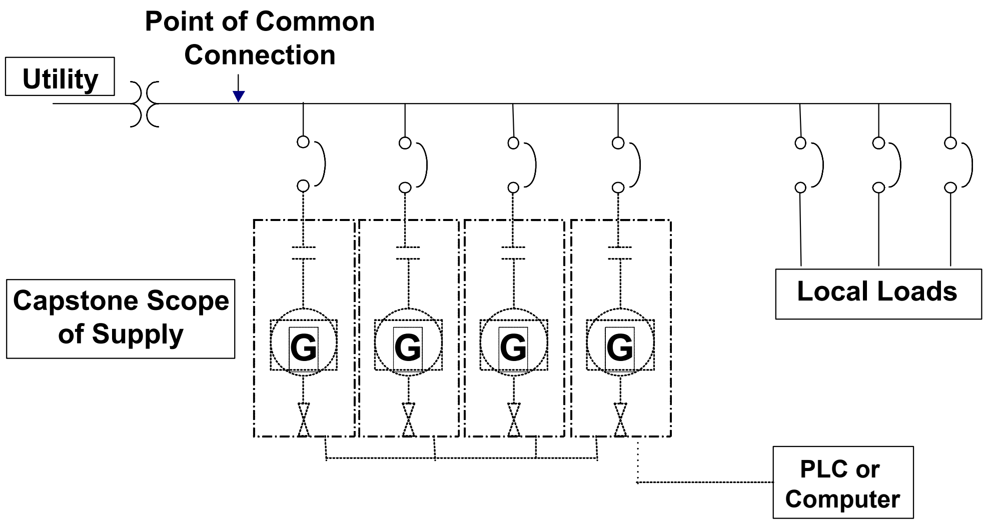


Figure 4-1. Typical MultiPac Interconnection

MultiPac Communications

Capstone microturbines use two digital communications connections between systems in a MultiPac to allow information to be shared:

- Load Control – Ethernet is used for command and control. Commands (i.e. start/stop, power demand) are input to the MultiPac Master. The Master then sends resulting commands to each microturbine in the MultiPac. The MultiPac Master routinely queries all microturbines connected to it for operational and fault data. Users can request data from any turbine through this Master.
- Inverter Synchronization – in Stand Alone mode, one turbine serves as an Inverter Master, passing voltage and frequency signals to all other turbines for synchronization using RS-485 signals. Note that the Inverter Master does not have to be the MultiPac Master, and requires no additional configuration other than setting up the MultiPac through the MultiPac Master. The RS-485 intra-cable harness also includes global E-stop and Battery Wake-up lines so that these hardwired commands can be immediately passed from the control Master to all other microturbines in the MultiPac. The wake-up signal can be passed from any unit to the rest.

Refer to Chapter 10: Communications in this document for details on these digital communications connections.

Configuring MultiPac Operation

Microturbines connected in a MultiPac must be told how to operate. This requires both hard wired connections in the User Connection Bay, and software commands from the front panel Display or through one of the serial communications ports using a PC with CRMS. To operate in MultiPac, the following needs to be done:

- Designate the MultiPac Master as turbine "1" using the Display or using a PC with CRMS. The MultiPac Master can be one of the microturbines or the Advanced Power Server. All other microturbines must be set to a unique addressing number.
- Enable MultiPac mode in each microturbine using the Display or using a PC with CRMS.

- Provide external control connections to the MultiPac Master. All Start/Stop, E-Stop, or other hardwired connections such as Stand Alone enable and Grid Connect enable inputs must be made in the Master's User Connection Bay. Note these physical connections must be transferred to a new MultiPac Master if the initial Master is taken out of service for any reason. Refer to Chapter 10: Communications in this document for details on pin connections.

MultiPac Operation

MultiPac operation is designed to maximize the combined output power of multiple microturbines. It also offers redundancy - if an individual turbine shuts down due to a fault (depending on the fault), remaining units will still continue to function.

Microturbines operating in a MultiPac operate in a Load Balanced configuration. A start command to the master is propagated to all systems in the MultiPac. All units start and stop as one unit. The power demand is shared evenly among all units in the MultiPac.

If any turbine, including the Master, experiences an operational fault such as a "6012 Fuel Fault", the remainder of the turbines continue operating - with the Master increasing the power demand to each of those systems to redistribute the load that the inoperative turbine no longer provides.

If the Master turbine experiences a hard failure in the power electronics, where no power exists to the electronics boards, command and control to the remaining turbines in the system will be made unavailable, and all operating turbines will be forced to generate power and retain functional settings at the last commanded values. Note that each subordinate turbine will still be able to detect, report, and act upon grid protective relay faults such as under/overvoltage and anti-islanding. In other words, microturbine Protective Relay functionality is non-volatile, fully independent of MultiPac operation, and remains operational on each microturbine at all times regardless of the microturbine's state or condition. Refer to the Chapter 9: Protective Relay Functions in this document for the protective functions provided.

Any microturbine, except the Master, can be MultiPac disabled to shut it down for repair or standard maintenance and keep the rest of the MultiPac operational. If a Master microturbine needs shutdown, the entire MultiPac must be shut down, and a new Master must be designated to continue MultiPac operation with the remaining microturbines. If a Dual Mode System Controller is installed, this wiring will also require relocation to the new Master microturbine. Note that the Master can also be an Advanced Power Sever, in which case any microturbine in the MultiPac can be taken out of service without impacting the remainder of the MultiPac.

Dispatch Modes

The sections above describe the two operating modes; Grid Connect and Stand Alone. Each of these operating modes can be dispatched in specific ways called Dispatch modes. Not all Dispatch modes will function with each operating mode. Furthermore, there are additional dispatch capabilities when an Advanced Power Server is the Master in a MultiPac group of microturbines. This section describes the capabilities of a C200 microturbine alone, or when a C200 is acting as the Master in a MultiPac. Refer to the Advanced Power Server Users Manual (400011) for details on the additional dispatch capabilities available when using the APS as the Master.

Table 4-1 summarizes the Dispatch modes to be described in detail below, and indicates which of these Dispatch modes apply to the two operating modes.

Table 4-1. Dispatch and Operating Modes

Dispatch Mode	Grid Connect	Stand Alone
Manual (User)	Yes	Yes
External Input (Remote)	Yes	Yes
Load Management	Yes	No

Manual (User)

Manual Dispatch is the initial factory setting for a newly shipped microturbine. Manual Dispatch mode allows the microturbine to be commanded ON/OFF manually, and then commanded to an output power level (Grid Connect mode) or voltage level (Stand Alone mode). In this case, the term "manually" means commanded locally through the Display panel, or remotely or locally through the serial communications port. The requested output power and/or voltage will be retained in non-volatile EEPROM memory for an indefinite period and applied at the next microturbine start-up if the values are entered through the Display panel or through the serial communications port using a PC.

Refer to the C200 User Manual (400008) and CRMS Technical Reference User's Edition (410013) for setting the Manual Dispatch mode, Power Demand, and Voltage levels. Note that this Manual Dispatch mode is also referred to as "User".

External Input (Remote)

The External Input mode allows an external signal to control the START/STOP status of the microturbine. Refer to the Chapter 10: Communications in this document for the specific User Connection Bay (UCB) pins and conditions required to start and stop the system. As with the Manual Dispatch mode, the power level (Grid Connect mode) or voltage level (Stand Alone mode) are stored in non-volatile memory. It is possible to set the External Input Control to have this input control both Grid Connect and Stand Alone modes (depending on which mode is enabled), or a mix of User and Remote control for the two operating modes Table 4-2 shows the four possible settings.

Refer to the C200 User Manual (400008) and CRMS Technical Reference User's Edition (410013) for setting the External Input Dispatch mode, Power Demand, and Voltage levels. Note that this External Input Dispatch mode is also referred to as "Remote".

Table 4-2. Start Input Setting Options for Manual and External Input

Start Input Setting	Grid Connect	Stand Alone
User	Display or Communications Port	Display or Communications Port
Remote	UCB Start/Stop Input	UCB Start/Stop Input
GC User / SA Remote	Display or Communications Port	UCB Start/Stop Input
SA User / GC Remote	UCB Start/Stop Input	Display or Communications Port

Load Management Modes

Load Management allows the user to optimize microturbine power generation efficiency while operating in Grid Connect mode. Load management does not apply to Stand Alone operation, since the output power is determined by the connected loads. The three Load Management modes available are Normal (or Base Load), Time of Use, and Load Following. Refer to the CRMS Technical Reference User's Edition (410013) for how to select and configure these Load Management modes.

Normal (Base Load)

Normal operating mode is the Initial factory setting for Grid Connect operation. When operating in Grid Connect mode, the Normal Dispatch mode generates power according to the stored Demand setting. The electric utility grid provides the remaining power to meet the total customer load. This dispatch mode is also referred to as "Base Load" mode. Figure 4-2 illustrates a C200 microturbine operating Grid Connect in this Base Load (Normal) mode. In the example, the microturbine supplies 200 kW base power and the electric utility grid supplies the rest of the load demand.

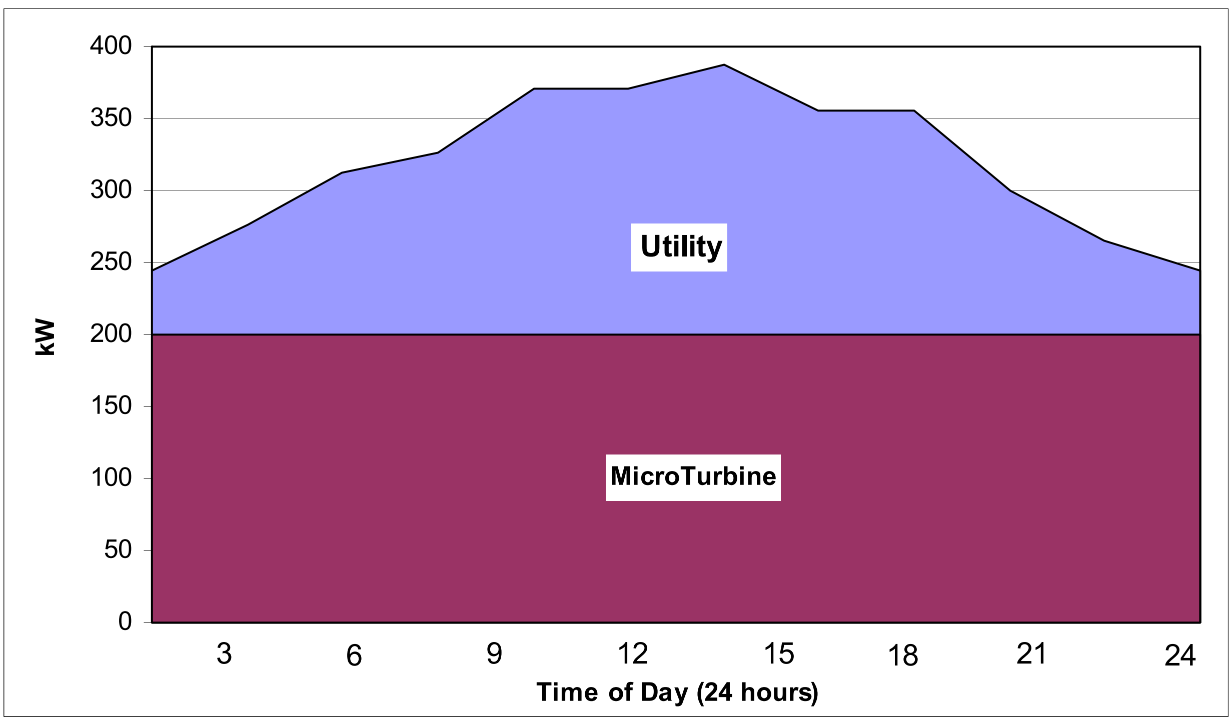


Figure 4-2. Grid Connect Operation in Normal (Base Load) Dispatch Mode

Time of Use

The Time of Use dispatch mode may be used for peak shaving during periods of the day when electricity from the utility is at a premium. Time of Use mode allows the user to selectively determine start/stop commands and/or power output levels for up to 20 timed events. Events are programmed by day of week, time of day, and power demand in any order, and sorted by time to determine event

order. Figure 4-3 illustrates how a C200 microturbine operating Grid Connect may be used in Time of Use mode.

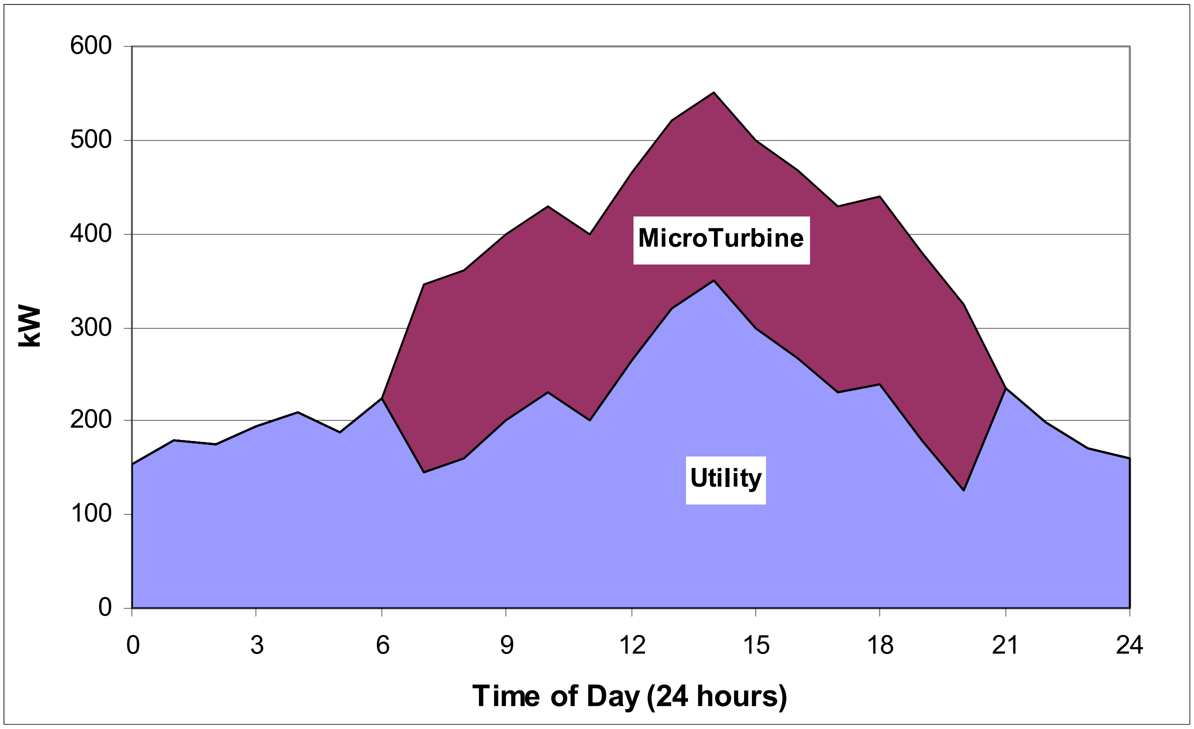


Figure 4-3. Grid Connect Operation in Time of Use Dispatch Mode

Time of Use setting is done using a PC with CRMS software. Refer to the CRMS Technical Reference User's Edition (410013) for configuring this dispatch mode.

Load Following

NOTE	Load Following requires an external power meter. The power meter is not supplied with the microturbine and must be connected between the microturbine and the electric service entrance. Refer to Chapter 10: Communications and Chapter 12: Installation in this document for additional details regarding meter requirements.

Load Following mode utilizes microturbine power in excess of the base power supplied by the utility grid (when required by external loads), allowing the microturbine to track local electrical loads, and supplying only as much power as is required. The microturbine regulates the utility power flow to an adjustable maximum - the utility power setpoint. If the local demand rises above this level by an adjustable amount for a selected time period, the microturbine is dispatched to supply the difference (up to its capacity). Figure 4-4 illustrates how a microturbine may be utilized in Load Following mode. In this illustration, the C200 microturbine supplies power above a utility power setpoint of 300 kW, up to its maximum power generation capability. Note that when actual load requirements fall below the 300 kW utility setpoint, the C200 microturbine stops exporting power.

When setting up an external power meter, it is also possible to connect a reverse power pulse signal to the C200 microturbine and use this input to automatically shut down the turbine to avoid exporting power to the utility grid. Refer to Chapter 9: Protective Relay Functions in this document for details.

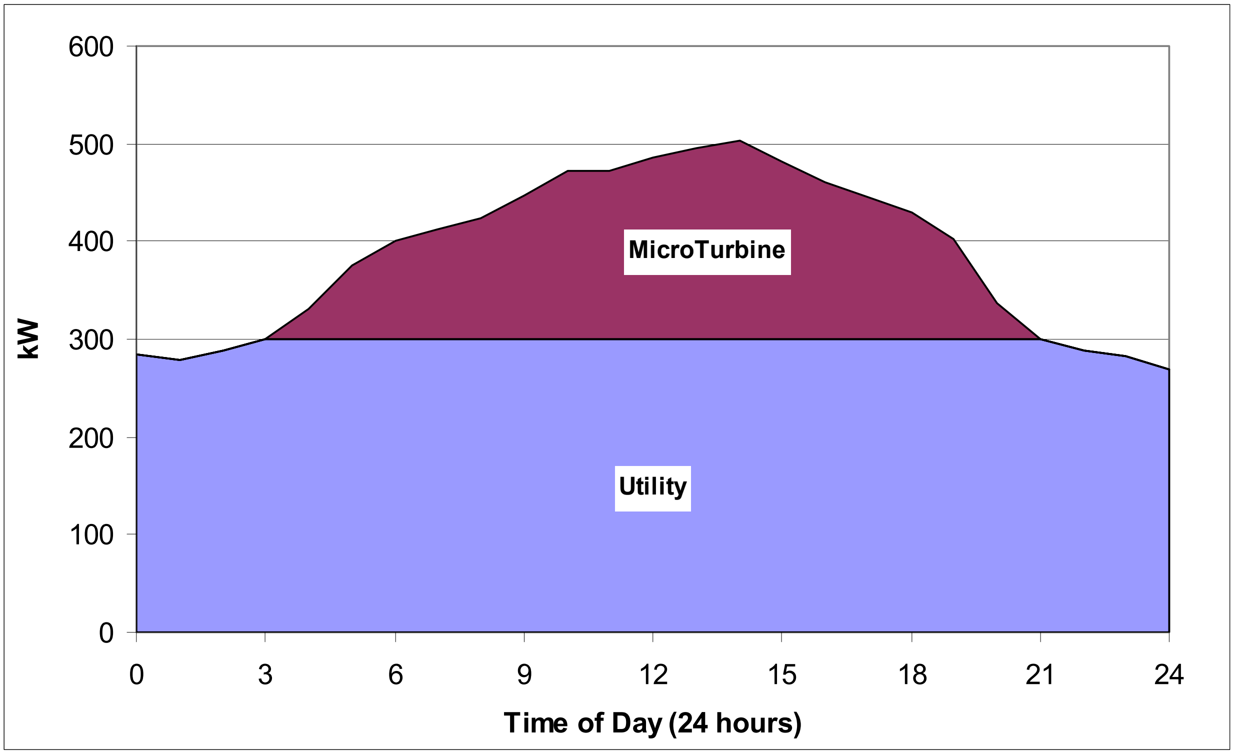


Figure 4-4. Grid Connect Operation in Load Following Dispatch Mode

The Load Following mode is used in the following situations: 1) To reduce peak demand charges (where applicable), 2) When power draw from the utility grid is limited by supply equipment capacity, or 3) If installed microturbine capacity exceeds the minimum local load demand and net revenue metering is not allowed by the utility.

Configuring Load Following mode requires a PC with CRMS software. The parameters that need to be configured using CRMS are as follows:

- Utility Power Setpoints adjust the allowable upper and lower utility power limits as controlled by the external power meter.
- Response Time sets the required time before the system responds with a new output command based on power meter signals. This acts as a filter to smooth out transients.
- Minimum Power Shutoff assigns an allowable power limit below the Utility Power Setpoint (based on kW demand) that the microturbine will operate before shutting down.
- Minimum Power Start-Up assigns a minimum power limit for the turbine to turn on (based on kW demand) if the system load exceeds the Utility Power Setpoint. This parameter is intended to maximize system efficiency by allowing the utility grid to continue operation instead of the microturbine at lower power levels. Together with the Minimum Power Shutoff, this setting provides a deadband to avoid frequent start-ups and shutdowns of the microturbine.
- Meter Constant specifies the number of watt-hours represented by a single pulse signal from the external power meter.

Refer to the CRMS Technical Reference User's Edition (410013) for how to configure these settings.

CHAPTER 5: BATTERY MANAGEMENT

Battery management consists of two elements; the controls management during the normal operational state and establishing equalization charges to maintain the life of the battery pack. The controls management is designed as an integrated element of the overall microturbine control system, and does not require any user input. It is described in the following section to help the user understand how the system functions. The equalization period does require user input, and the period is dependent on the environmental conditions and load profiles of the application.

In Stand Alone operation, the primary functions of the battery are:

- Provide power during onload transients
- Accept power during offload transients
- Provide power while starting and stopping the microturbine
- Provide power during standby state.

Battery performance is tied to regularly scheduled maintenance and equalization charging to optimize battery life and ensure that the battery performs as designed. Refer to the Battery Life section of Chapter 11: Maintenance for recommended preventive maintenance.

Battery Charge Management

Upon a Start command, the system leaves the Standby state to power up microturbine components to operational levels before transitioning to the Run state, where battery charging may again occur. Once started in Stand Alone mode, the microturbine will not advance to the Stand Alone Load state until the battery state-of-charge is at least 60% (note that state-of-charge less than 60% will only occur under conditions of poor maintenance, multiple subsequent fault cycles or end of battery life). After this state is achieved, the output contactor is closed and the microturbine begins producing power for connected loads.

The C200 microturbine system is designed to keep the battery at 95 to100 percent state-of-charge during Load state operation to allow for sourcing power for load transients. If a user-initiated STOP is performed, the system immediately enters the recharge state, to ensure the battery is over 90 percent state-of-charge before entering the Cooldown state**.** Normally, the system will take approximately twenty (20) minutes to recharge the battery following a STOP command. On transition to cooldown, fuel is commanded off and the microturbine spins down, but remains rotating to provide airflow over engine components for cooling. After Cooldown is complete, the microturbine enters a short Shutdown state before finally entering the Standby state. No battery charging is performed while in Standby.

If the system is not commanded ON during a user-selectable time period, the system will automatically enter a minimum battery drain state called Sleep state. This time period is called the Auto Sleep Time. Putting the battery in Sleep state can preserve battery charge for up to six months (life is based on ambient temperatures). Refer to the CRMS Technical Reference User Edition (410013) for how to set the Auto Sleep Time.

Note that the batteries must be at least 90% state-of charge for the system to achieve the full Stand Alone step load capabilities defined in Chapter 8: Electrical Ratings. Perform an

equalization charge (refer to the next section) prior to commanding the system to the Stand Alone Load state if the application requires maximum step load capability.

Equalization Charge

The microturbine will perform an equalization charge cycle periodically to maintain an equal charge in all battery cells. This equalization charge may be automated or commanded manually (charges to 100% state-of-charge) and may take up to four hours. Equalization charging may be disallowed during certain hours of certain days of the week to prevent interference with dispatch schedules.

In Stand Alone mode, the software will automatically initiate an equalization charge based on watt-hours usage of the battery pack. For full time Stand Alone operation, this occurs approximately once per week. A small amount of power produced by the microturbine is provided to the battery pack to bring it up to 100 percent state-of-charge. Note that this power is not available to output loads, and the user may program allowable times for this charge to take place.

In Dual Mode configuration, the system will automatically initiate the equalization charge during the Grid Connect Load state every 7-30 days based on the Grid Batt Eq Chg days value. If an equalization charge is required, the system will initiate a battery wake-up, perform the 4-hour charge, and then put the battery pack back into sleep mode. If a charge is not required, the system will put the battery into sleep mode after 15 minutes in the Grid Connect Load state. As set by the factory, charging is allowed any time of the day. Days or times should be reduced to prevent charging from occurring during peak demand times. A minimum of one 4-hour window during microturbine operating hours is required to maintain battery life.

NOTE	Once an equalization charge has started, it will complete regardless of the day and hour of the permission set-up.

CHAPTER 6: FUEL REQUIREMENTS

Capstone C200 microturbines are available in several versions that can operate on natural gas, and medium BTU gasses (such as from a landfill or anaerobic digester). Capstone has defined these fuel types according to energy content, Wobbe index, and other characteristics in the Fuel Requirements Specification (410002). Table 6-1 summarizes the energy content and inlet fuel pressure requirements for each C200 version.

Table 6-1. Fuel Input Requirements

C200 Version	Inlet Pressure Range	Fuel Type	Fuel Energy Content Range [HHV]
High Pressure NG	75 - 80 psig (517 – 552 kPaG)	Natural Gas	30,700 – 47,500 kJ/m^3 (825 – 1,275 Btu/scf)
Low Pressure NG	0.25 – 5 psig (1.8 – 103 kPaG)		
Landfill	75 – 80 psig (517 – 552 kPaG)	Landfill Gas	13,000 – 22,300 kJ/m^3 (350 – 600 Btu/scf)
Digester	75 – 80 psig (517 – 552 kPaG)	Digester Gas	20,500 – 32,600 kJ/m^3 (550 – 875 Btu/scf)

The fuel provided to each C200 microturbine must meet the inlet pressure requirements under all operating conditions. Fuel flow during on-loads can be up to one and one half times the nominal steady state value. Nominal steady state fuel flow [HHV] at full power and ISO conditions for all C200 versions is 2,400,000 kJ/hr (2,280,000 Btu/hr). The ratio of higher heating value (HHV) to lower heating value (LHV) is assumed to be 1.1 for all fuel types.

Maximum fuel contaminants are defined in the Fuel Requirements Specification (410002) for each fuel type. Some of the allowable contaminants depend on the specific microturbine model rather than the fuel type definition. For the C200 microturbine family, the maximum allowable sulfur content (expressed as hydrogen sulfide) is shown in Table 6-2.

Table 6-2. Maximum Sulfur Content

C200 Version	Fuel Type	Maximum Sulfur Content (expressed as H_2S)
High Pressure NG	Natural Gas	5 ppm
Low Pressure NG		
Landfill	Landfill Gas	5,000 ppm
Digester	Digester Gas	5,000 ppm

The Landfill/Digester Gas Use Application Guide (480002) contains advice and examples for designing fuel treatment systems for landfill and digester gas applications. In addition to this specific guidance, Table 6-3 summarizes the requirements to be met at the inlet to each microturbine for all fuel types.

Table 6-3. General Fuel Requirements for All Fuel Types

Fuel Characteristic	Requirement
Maximum Temperature	50°C (122°F)
Minimum Temperature	Greater of: -20°C (-4°F) or 10°C (18°F) above fuel dew point
Inlet Pressure Fluctuations	< 1 psi/sec (1)
Particulates	95% of particulates and vapors < 10μm (2)
Lubricating Oils (e.g. from external compressor	none

Notes:

(1) Capstone recommends a regulator be provided at each microturbine inlet to mitigate against pressure disturbances in a common fuel header for all high pressure systems. Note that the inlet pressure ranges in Table 6-1 are after the addition of any regulator.

(2) Capstone recommends use of an external fuel filter in most cases. A common filter for a header feeding all microturbines is acceptable. Use a 10 μm or finer filter element. A filter may not be required for U.S. installations using commercial natural gas.

The C200 microturbine system must be set up with the correct fuel settings for the specific fuel type. Factory settings are adjusted for the nominal fuel type. A Capstone Authorized Service Provider can make field setting changes, if necessary, using CRMS.

Refer to the C200 Outline & Installation drawing (523005) for fuel inlet connection details.

CHAPTER 7: PERFORMANCE

The information in this section is intended to provide guidance for estimating the performance characteristics of Capstone C200 microturbines under different operating conditions of temperature, elevation, load, inlet restriction, and exhaust back pressure.

Power Output

Gas turbines are often called “mass flow devices” due to the fact that they take in significantly more air than is required for stoichiometric combustion. This results in a thermodynamic cycle that is dependent on air density effects of temperature and elevation. Microturbine systems have been designed with this characteristic in mind, and the size and capability of the generator and associated power electronics are matched to the micro gas turbine output. The industry standard for gas turbines is to publish their nameplate rated output based on ISO condition of 15°C (59°F) and 60% relative humidity at sea level. Capstone microturbines take the high frequency output of the generator that is connected to a common shaft with the gas turbine power section and use power electronics to rectify it to DC, and then invert back to useable AC power at 50 or 60Hz. Since the generator windings and power electronics outputs are limited by their current carrying capacity, the net microturbine power output is typically maintained at some maximum level as temperature decreases, even though the gas turbine could produce additional power. Figure 7-1 shows an example of the published power output of a Capstone 200kW microturbine system as a function of temperature.

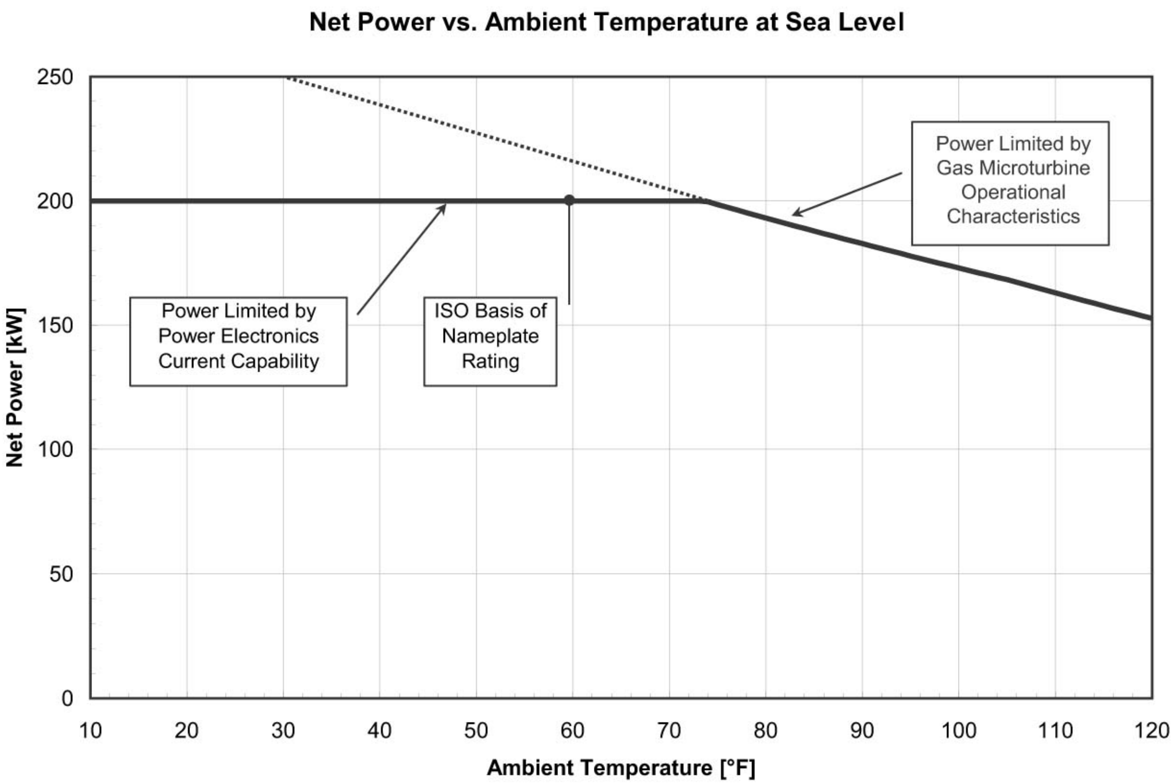


Figure 7-1. Net Power vs Ambient Temperature

Efficiency and Fuel Heating Value

Gas turbines combust fuel to expand the incoming air, drive a turbine wheel to generate torque, and thereby produce mechanical power. The recuperator in the Capstone microturbine transfers some of the energy in the exhaust leaving the turbine section to preheat incoming compressed air, thereby reducing the amount of fuel needed to expand the air driving the turbine. This results in increased efficiency. However, the exhaust leaving the recuperator is still at sufficiently high temperature that the products of combustion remain in vapor state.

The products of combustion for a hydrocarbon fuel are carbon dioxide (CO_2) and water (H_2O). The heating value of the fuel used in any engine can be calculated two ways;

1. Lower Heating Value – the energy associated with condensation of water vapor is not considered.
2. Higher Heating Value – the energy of water condensation taken back to ambient temperature is added to the lower heating value of the fuel.

Since the microturbine exhaust never gets cool enough to condense water and take advantage of that additional energy of condensation, the industry standard is to use the lower heating value when calculating efficiency. This is typical for all prime movers, whether turbines, reciprocating engines, or fuel cells. When purchasing fuel, however, the total available energy content is usually referenced; meaning the higher heating value. This technical reference may provide information in either unit of measure, but will always signify whether it is lower heating value (LHV) or higher heating value (HHV). For gaseous fuels, the ratio of higher heating value to lower heating value is assumed to be 1.1.

Heat rate is an industry standard term for the amount of energy input for a unit electrical output, and is often shown in British Thermal Units (BTUs) per kilowatt-hour of electrical output. There are 3,413 BTUs per kWh. The net heat rate is based as electrical output (kWh) at the user terminals of the C200 microturbine. The generator heat rate is based on the electrical output at the generator terminals, prior to the digital power electronics.

Fuel Parameters

Refer to Chapter 6: Fuel Requirements for detailed information regarding fuel parameters for the Model C200 microturbine.

Exhaust Characteristics

The exhaust information included in this section represents nominal temperature, mass flow, and energy. Any fluid passing through a confined space (such as hot exhaust moving through a duct or heat exchanger) will have some distribution of velocity and temperature. Testing using probes for temperature or mass flow will therefore show differences, depending on where in the flow the measurements are taken. The values in this section should therefore be considered averages across the exhaust outlet of the microturbine. The exhaust energy is calculated without considering the energy of condensation, and is therefore based on lower heating value.

The microturbine control system uses turbine exit temperature (TET) as part of its control function, and attempts to maintain TET to a preset value for most operating conditions. The exhaust at the microturbine outlet is lower than this TET, since some energy has been extracted in the recuperator to preheat incoming compressed air. As a simple approximation, turbine efficiency depends on ambient temperature therefore, the higher the efficiency the lower the exhaust temperature. Efficiency does not change significantly with change in elevation. Therefore, to estimate exhaust characteristics at elevation, consider the exhaust temperature to be the same as for a given temperature at sea level and adjust the mass flow rate to reflect changes in power output. More details on how to calculate exhaust characteristics are described below.

ISO Full Load Performance

A summary of nominal performance at full load power and ISO conditions for Capstone C200 microturbines is shown in Table 7-1.

Table 7-1. Capstone Model C200 Microturbine Performance Summary

Parameter	C200 Low Pressure NG	All Other C200
Net Power Output	190 (+0/-4) kW net	200 (+0/-4) kW net
Net Efficiency (LHV)	31 (± 2)%	33 (± 2)%
Nominal Net Heat Rate (LHV)	11,600 kJ/kWh (11,000 Btu/kWh)	10,900 kJ/kWh (10,300 Btu/kWh)
Nominal Generator Heat Rate (LHV)	10,700 kJ/kWh (10,200 Btu/kWh)	10,200 kJ/kWh (9,700 Btu/kWh)
Nominal Steady State Fuel Flow (HHV) (1) (2)	2,400,000 kJ/hr (2,280,000 Btu/hr)	2,400,000 kJ/hr (2,280,000 Btu/hr)

Notes:

(1) The ratio of Higher Heating Value (HHV) to Lower Heating Value (LHV) is assumed to be 1.1.

(2) Onload fuel flows can be up to two times higher than the steady state values.

How to Use This Section

The following pages present several tables and graphs for determining the nominal net power output, efficiency, and exhaust characteristics for various operating conditions.

Table 7-5 at the end of this section provides an example calculation. The basic method is summarized below:

- Look up the efficiency, exhaust temperature, and exhaust mass flow for a given temperature using Table 7-2.
- Estimate the power output using Figure 7-2 for a given temperature and elevation.
- Apply inlet pressure loss power and efficiency correction factors (if any) using Table 7-3.
- Apply back pressure power and efficiency correction factors (if any) using Table 7-4.
- Calculate nominal net power output and fuel input for the given operating conditions.
- Define parasitic loads (Fuel Gas Booster, water pump, etc.).
- Estimate exhaust temperature and flow for the given operating conditions.

In addition to the steps above, tolerances for a given application must be considered. Refer to the Consider Tolerances section of this document for more information.

Ambient Temperature Table

Nominal net power output, efficiency, and exhaust characteristics versus ambient temperature at sea level for the Capstone C200 high pressure natural gas model microturbine are presented in Table 7-2. These values are estimated from nominal performance curves.

Table 7-2. Nominal Net Power Output and Efficiency versus Ambient Temperature

Ambient Temp (°F)	Net Power (kW)	Net Efficiency (%)	Exhaust Temp (°F)	Exhaust Mass Flow Rate (lbm/s)	Exhaust Energy Rate (kW/hr LHV)	Fuel Flow Energy Rate (Btu/hr LHV)	Net Heat Rate (Btu/kWhr LHV)
-4	200.0	34.3	431.9	3.04	375.1	1,991,249	9,956
-3	200.0	34.3	433.4	3.03	374.9	1,991,158	9,956
-2	200.0	34.3	434.9	3.03	374.8	1,991,069	9,955
-1	200.0	34.3	436.5	3.02	374.6	1,990,982	9,955
0	200.0	34.3	438.0	3.02	374.4	1,990,898	9,954
1	200.0	34.3	439.6	3.01	374.3	1,990,815	9,954
2	200.0	34.3	441.1	3.01	374.1	1,990,735	9,954
3	200.0	34.3	442.6	3.00	373.9	1,990,657	9,953
4	200.0	34.3	444.2	3.00	373.8	1,990,581	9,953
5	200.0	34.3	445.7	2.99	373.6	1,990,532	9,953
6	200.0	34.3	447.2	2.99	373.5	1,990,511	9,953
7	200.0	34.3	448.8	2.99	373.3	1,990,491	9,952
8	200.0	34.3	450.3	2.98	373.2	1,990,474	9,952
9	200.0	34.3	451.9	2.98	373.1	1,990,458	9,952
10	200.0	34.3	453.4	2.97	372.9	1,990,444	9,952
11	200.0	34.3	454.9	2.97	372.8	1,990,432	9,952
12	200.0	34.3	456.5	2.96	372.6	1,990,422	9,952
13	200.0	34.3	458.0	2.96	372.5	1,990,413	9,952
14	200.0	34.3	459.5	2.95	372.3	1,990,406	9,952
15	200.0	34.3	461.1	2.95	372.2	1,990,401	9,952
16	200.0	34.3	462.6	2.94	372.1	1,990,398	9,952
17	200.0	34.3	464.1	2.94	371.9	1,990,396	9,952
18	200.0	34.3	465.7	2.93	371.8	1,990,396	9,952
19	200.0	34.3	467.2	2.93	371.6	1,992,466	9,962
20	200.0	34.2	468.7	2.93	371.9	1,994,540	9,973
21	200.0	34.2	470.3	2.93	372.3	1,996,618	9,983
22	200.0	34.2	471.8	2.93	372.8	1,998,701	9,994
23	200.0	34.1	473.3	2.93	373.2	2,000,788	10,004
24	200.0	34.1	474.9	2.93	373.6	2,002,879	10,014
25	200.0	34.0	476.4	2.93	374.1	2,004,975	10,025
26	200.0	34.0	477.9	2.93	374.5	2,007,075	10,035
27	200.0	34.0	479.4	2.93	374.9	2,009,180	10,046
28	200.0	33.9	481.0	2.93	375.4	2,011,289	10,056
29	200.0	33.9	482.5	2.93	375.8	2,013,402	10,067
30	200.0	33.9	484.0	2.93	376.3	2,015,520	10,078
31	200.0	33.8	485.6	2.93	376.7	2,017,643	10,088
32	200.0	33.8	487.1	2.93	377.1	2,019,769	10,099
33	200.0	33.8	488.6	2.93	377.6	2,021,901	10,110
34	200.0	33.7	490.1	2.93	378.0	2,024,037	10,120
35	200.0	33.7	491.6	2.93	378.4	2,026,177	10,131
36	200.0	33.7	493.2	2.93	378.9	2,028,322	10,142
37	200.0	33.6	494.7	2.93	379.3	2,030,471	10,152

Continued on next page

Ambient Temp (°F)	Net Power (kW)	Net Efficiency (%)	Exhaust Temp (°F)	Exhaust Mass Flow Rate (lbm/s)	Exhaust Energy Rate (kW/hr LHV)	Fuel Flow Energy Rate (Btu/hr LHV)	Net Heat Rate (Btu/kWhr LHV)
38	200.0	33.6	496.2	2.93	379.7	2,032,625	10,163
39	200.0	33.5	497.8	2.93	380.2	2,034,784	10,174
40	200.0	33.5	499.6	2.93	380.9	2,036,947	10,185
41	200.0	33.5	501.5	2.93	381.6	2,039,114	10,196
42	200.0	33.4	503.3	2.93	382.3	2,041,287	10,206
43	200.0	33.4	505.1	2.93	383.0	2,043,464	10,217
44	200.0	33.4	507.0	2.93	383.7	2,045,645	10,228
45	200.0	33.3	508.8	2.93	384.4	2,047,832	10,239
46	200.0	33.3	510.7	2.93	385.1	2,050,023	10,250
47	200.0	33.3	512.6	2.93	385.8	2,052,218	10,261
48	200.0	33.2	514.4	2.93	386.5	2,054,419	10,272
49	200.0	33.2	516.3	2.93	387.3	2,056,624	10,283
50	200.0	33.2	518.2	2.93	388.0	2,058,834	10,294
51	200.0	33.1	520.1	2.93	388.7	2,061,048	10,305
52	200.0	33.1	522.0	2.93	389.5	2,063,268	10,316
53	200.0	33.0	523.9	2.93	390.2	2,065,492	10,327
54	200.0	33.0	525.8	2.93	391.0	2,067,721	10,339
55	200.0	33.0	527.8	2.93	391.8	2,069,954	10,350
56	200.0	32.9	529.7	2.93	392.5	2,072,193	10,361
57	200.0	32.9	531.6	2.93	393.3	2,074,436	10,372
58	200.0	32.9	533.5	2.93	394.0	2,076,693	10,383
59	200.0	32.8	535.1	2.93	394.6	2,078,942	10,395
60	200.0	32.8	536.8	2.93	395.1	2,081,198	10,406
61	200.0	32.8	538.4	2.93	395.6	2,083,460	10,417
62	200.0	32.7	540.1	2.93	396.2	2,085,727	10,429
63	200.0	32.7	541.7	2.93	396.7	2,088,000	10,440
64	200.0	32.7	543.4	2.93	397.2	2,090,278	10,451
65	200.0	32.6	545.0	2.93	397.8	2,092,560	10,463
66	200.0	32.6	546.6	2.93	398.3	2,094,848	10,474
67	200.0	32.5	548.2	2.93	398.8	2,097,141	10,486
68	200.0	32.5	549.9	2.93	399.3	2,099,439	10,497
69	200.0	32.5	551.5	2.93	399.8	2,101,742	10,509
70	200.0	32.4	553.1	2.93	400.3	2,104,050	10,520
71	200.0	32.4	554.8	2.93	400.9	2,106,362	10,532
72	200.0	32.4	556.5	2.93	401.5	2,108,680	10,543
73	200.0	32.3	558.2	2.93	402.1	2,111,004	10,555
74	199.7	32.3	559.7	2.93	402.5	2,110,939	10,572
75	198.6	32.2	560.6	2.93	402.5	2,102,499	10,589
76	197.4	32.2	561.5	2.92	402.1	2,094,133	10,606
77	196.4	32.1	562.4	2.92	401.3	2,085,842	10,623
78	195.3	32.1	563.3	2.91	400.5	2,077,624	10,640
79	194.2	32.0	564.2	2.91	399.7	2,069,477	10,657
80	193.1	32.0	565.1	2.91	398.9	2,061,398	10,675

Continued on next page

Ambient Temp (°F)	Net Power (kW)	Net Efficiency (%)	Exhaust Temp (°F)	Exhaust Mass Flow Rate (lbm/s)	Exhaust Energy Rate (kW/hr LHV)	Fuel Flow Energy Rate (Btu/hr LHV)	Net Heat Rate (Btu/kWhr LHV)
81	192.1	31.9	566.0	2.90	398.2	2,053,386	10,692
82	191.0	31.9	566.8	2.89	397.4	2,045,439	10,709
83	190.0	31.8	567.7	2.89	396.6	2,037,557	10,727
84	188.9	31.8	568.5	2.88	395.7	2,029,736	10,744
85	187.9	31.7	569.4	2.88	394.9	2,021,975	10,762
86	186.9	31.7	570.2	2.87	394.1	2,014,237	10,779
87	185.8	31.6	571.1	2.87	393.3	2,006,482	10,797
88	184.8	31.6	571.9	2.86	392.5	1,998,785	10,815
89	183.8	31.5	572.7	2.86	391.6	1,991,144	10,832
90	182.8	31.5	573.5	2.85	390.8	1,983,558	10,850
91	181.8	31.4	574.3	2.85	389.9	1,976,025	10,868
92	180.8	31.4	575.1	2.84	389.0	1,968,545	10,886
93	179.8	31.3	575.8	2.84	388.1	1,960,963	10,904
94	178.8	31.2	576.6	2.83	387.1	1,953,318	10,922
95	177.9	31.2	577.3	2.83	386.1	1,945,733	10,940
96	176.9	31.1	578.0	2.82	385.2	1,938,204	10,958
97	175.9	31.1	578.7	2.82	384.2	1,930,731	10,977
98	174.9	31.0	579.4	2.81	383.2	1,923,312	10,995
99	174.0	31.0	580.1	2.81	382.2	1,915,946	11,013
100	173.0	30.9	580.8	2.80	381.2	1,908,632	11,032
101	172.1	30.9	581.5	2.79	380.2	1,901,369	11,050
102	171.1	30.8	582.2	2.79	379.2	1,894,155	11,069
103	170.2	30.8	582.8	2.78	378.1	1,886,989	11,087
104	169.3	30.7	583.5	2.78	377.1	1,879,871	11,106
105	168.3	30.7	584.1	2.77	376.1	1,872,796	11,125
106	167.3	30.6	584.6	2.77	374.7	1,863,936	11,143
107	166.2	30.6	585.1	2.76	373.3	1,855,102	11,162
108	165.1	30.5	585.5	2.75	371.9	1,846,306	11,181
109	164.1	30.5	586.0	2.74	370.5	1,837,550	11,200
110	163.0	30.4	586.4	2.74	369.1	1,828,834	11,219
111	162.0	30.4	586.8	2.73	367.7	1,820,157	11,238
112	160.9	30.3	587.3	2.72	366.3	1,811,518	11,258
113	159.9	30.3	587.7	2.71	364.8	1,802,918	11,277
114	158.8	30.2	588.1	2.71	363.4	1,794,357	11,296
115	157.8	30.2	588.5	2.70	362.0	1,785,834	11,315
116	156.8	30.1	588.9	2.69	360.5	1,777,348	11,335
117	155.8	30.1	589.3	2.69	359.1	1,768,900	11,354
118	154.8	30.0	589.7	2.68	357.6	1,760,490	11,374
119	153.8	30.0	590.1	2.67	356.2	1,752,116	11,394
120	152.8	29.9	590.5	2.66	354.7	1,743,780	11,413
121	151.8	29.9	590.8	2.66	353.3	1,735,480	11,433
122	150.8	29.8	591.2	2.65	351.8	1,727,216	11,453

Elevation Derating

Elevation affects power output by changing the density of the air. Figure 7-2 provides expected maximum power output for several elevations versus ambient temperature. Values shown assume nominal engine output, and are based on the 1976 US Standard Atmosphere model to correlate air density to elevation. Electrical efficiency is not strongly dependent on elevation, so the nominal efficiency values listed in Table 7-2 can be used to estimate fuel consumption at any elevation for a given ambient temperature. A method to estimate exhaust characteristics is provided below.

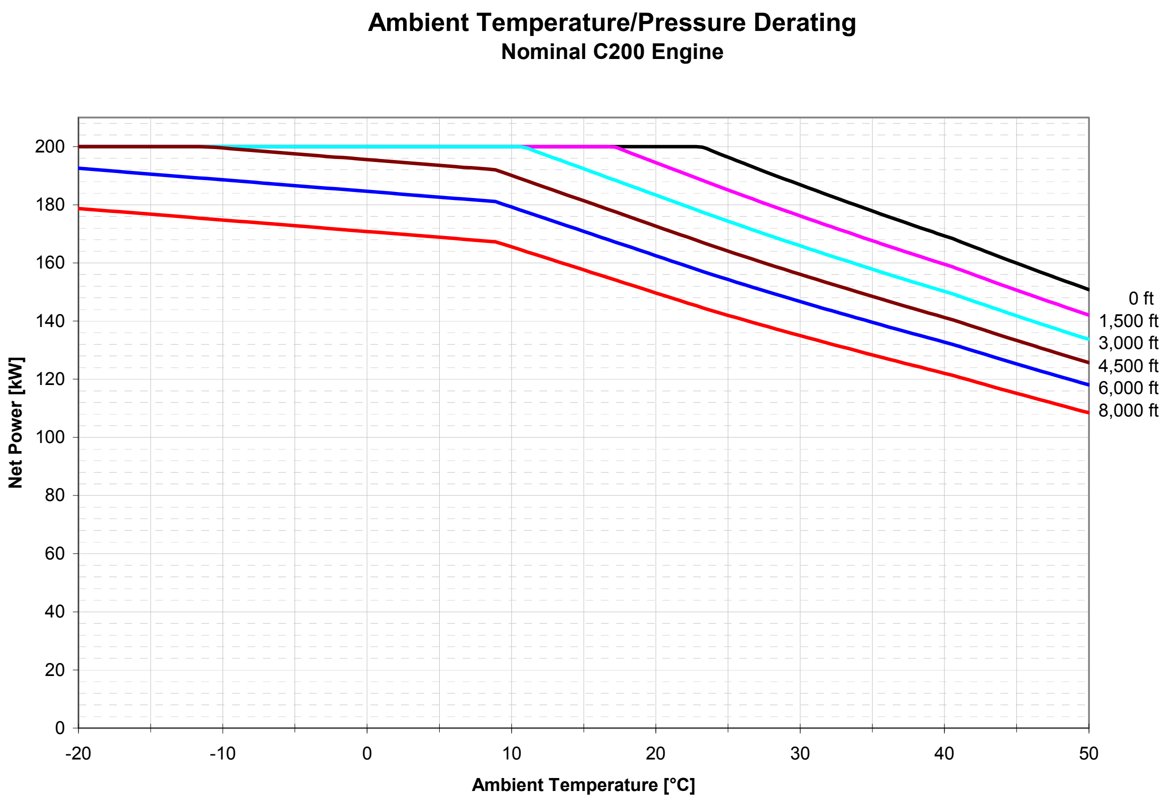


Figure 7-2. Ambient Elevation vs. Temperature Derating

Inlet Pressure Loss Correction Factors

Air inlet design can affect engine performance. The amount of air inlet filter debris can also affect engine performance for all engine applications. The maximum allowable inlet pressure loss is 10 inches of water.

Table 7-3 presents the nominal fraction of ISO zero inlet pressure loss power and efficiency versus inlet pressure loss at ISO ambient conditions for the Model C200 microturbine. These values are estimated from nominal performance curves. Interpolate, if needed, for inlet pressure losses between those listed in Table 7-3.

The inlet loss power and efficiency correction factors are defined as follows:

$$\text{Power CF} = \frac{\text{Power Output}}{\text{Power Output at zero (0) Inlet Loss}}$$

$$\text{Efficiency CF} = \frac{\text{Efficiency}}{\text{Efficiency at zero (0) Inlet Loss}}$$

Table 7-3. Nominal Fraction of ISO Zero Inlet Pressure Loss Power and Efficiency

Inlet Pressure Loss (Inches of Water)	Inlet Pressure Loss Power CF	Inlet Pressure Loss Efficiency CF
0.0	1.000	1.000
1.0	0.994	0.998
2.0	0.987	0.995
3.0	0.981	0.993
4.0	0.974	0.990
5.0	0.968	0.988
6.0	0.961	0.986
7.0	0.955	0.983
8.0	0.949	0.981
9.0	0.942	0.978
10.0	0.936	0.976

Back Pressure Correction Factors

The maximum allowable exhaust back pressure for a C200 microturbine is eight inches of water. Nominal fraction of ISO net power output and efficiency versus back pressure is presented in Table 7-4. These values are estimated from nominal performance curves. Interpolate, if needed, for back pressure values between those listed in Table 7-4.

The back pressure power and efficiency correction factors are defined as follows:

$$\text{Power CF} = \frac{\text{Power Output}}{\text{Power Output at zero (0) Back Pressure}}$$

$$\text{Efficiency CF} = \frac{\text{Efficiency}}{\text{Efficiency at zero (0) Back Pressure}}$$

Table 7-4. Nominal Fraction of ISO Net Power Output and Efficiency versus Exhaust Back Pressure at ISO Ambient Conditions

Back Pressure (Inches of Water)	Back Pressure Power CF	Back Pressure Efficiency CF
0.0	1.000	1.000
1.0	0.996	0.998
2.0	0.992	0.995
3.0	0.988	0.993
4.0	0.985	0.990
5.0	0.981	0.988
6.0	0.977	0.985
7.0	0.973	0.983
8.0	0.969	0.981

Calculate Nominal Net Power and Fuel Input

The net power output can be estimated from previous steps by multiplying the inlet and exhaust back pressure correction factors times the estimated power output from Figure 7-2. For example, using Figure 7-2 for 30°C (86°F) temperature and 1,500 ft elevation, the estimated nominal power output is 176 kW. If the inlet pressure loss is 2 inches of water column, then the power correction factor from Table 7-4 is .987. For a 3 inch water column back pressure drop, the correction factor from Table 7-4 is .988. Use the following equation to estimate the net power:

kW (net) = kW (elevation & temp) X Inlet CF X Back Pressure CF

Continuing the example, the 176 kW gross power output becomes a net power of 172 kW after multiplying by the inlet and exhaust backpressure correction factors.

A similar calculation can be done for efficiency. Referring to Table 7-2 and using the same ambient temperature of 30°C (86°F), the efficiency is tabulated as 31.7%. For an inlet pressure loss of 2 inches of water column, the efficiency correction factor from Table 7-3 is .995. For an exhaust backpressure of 3 inches of water column, the efficiency correction factor from Table 7-4 is .993. Use the following equation to estimate the net efficiency:

Efficiency (net) = Efficiency (ambient temp) X Inlet CF X Back Pressure CF

Continuing the example, the 31.7% gross efficiency becomes a net efficiency of 31.3% after multiplying by the inlet and exhaust correction factors.

The fuel input can now be estimated from the net power and efficiency using the following equation:

$$\text{Net Fuel Input [kW]} = \frac{\text{Net Power Output [kW]}}{\text{Net Efficiency [\%]}}$$

For the example given above with net output power of 172 kW and net efficiency of 31.3%, the estimated fuel input is 550 kW. To convert this to English units, multiply the kW of fuel times 3,413 BTU per kWh to get 1,880,000 BTU/hr.

Parasitic Loads

The impact of parasitic loads on useable power output should be considered. For the low pressure natural gas model C200, the internal fuel gas booster requires approximately 10 kW of power under most operating conditions. This is because it is always trying to maintain fuel inlet pressure to the turbine regardless of microturbine output power requirements or inlet fuel pressure.

So for any estimated net power output, subtract 10 kW for a low pressure natural gas model C200. Other values may need to be provided if an external gas compressor is used, or other system parasitic loads need to be considered. Using the example above for of 30°C (86°F) ambient, 1,500 ft elevation, and inlet and back pressure correction factors applied, the 172 kW net output becomes a useable power output for customer loads of 162 kW after subtracting 10 kW for a fuel gas booster.

Estimate Exhaust Characteristics

The temperature and mass flow for the exhaust can now be estimated, using the information calculated above for net power plus the exhaust characteristics at sea level. The primary impacts to exhaust characteristics are ambient temperature (which impacts electrical efficiency) and net electrical output. A simple method to approximate the exhaust characteristics is to define the exhaust temperature as if the system were operating at sea level, and then make adjustments to the exhaust mass flow to reflect changes in the net electrical output due to elevation, inlet pressure loss, and exhaust backpressure. An additional reduction of 0.5 percent per 1,000 ft elevation should be added to the exhaust mass flow calculation.

So, for a given ambient condition use the following equations:

$$\text{Exhaust Temp (elevation)} = \text{Exhaust Temp (sea level)}$$

$$\text{Exhaust Flow (elevation)} = \text{Flow (sea level)} \times \frac{\text{kWe (elevation)}}{\text{kWe (sea level)}} \times \left[1 - \frac{0.005 \times \text{Elevation [ft]}}{1{,}000}\right]$$

For the example above at 30°C (86°F) and 1,500 ft elevation, the exhaust temperature from Table 7-2 is 570°F and exhaust flow is 2.87 lbm/s. From Table 7-2 the electric power output at sea level is 187kW, and from Figure 7-2 the electric power output at 1,500ft elevation is 176kW. Using the equations above:

Exhaust Temp (elevation) = 570°F

Exhaust Flow (elevation) = 2.70 lbm/s

Example Calculations

Table 7-5 provides an example calculation for a C200 low pressure natural gas microturbine operating at 30°C (86°F), 1,500 ft elevation, 2 inches WC inlet pressure loss, and 3 inches WC exhaust back pressure.

Table 7-5. Example Calculation for Nominal Power, Efficiency, and Exhaust Characteristics

Steps	Rule	Example
1. Define output power, efficiency, and exhaust characteristics at ambient temperature and sea level	Use Table 7-2	For 86°F (30°C) Ambient: Output = 186 kW electric Efficiency = 31.7% Exhaust Temp = 570°F Exhaust Flow = 2.87 lbm/s
2. Estimate electric output at the given elevation	Use Figure 7-2	for 1,500ft Elevation: Output = 176 kW electric
3. Estimate Power and Efficiency Correction Factors for Inlet Pressure Loss	Use Table 7-3	for 2 inch WC: Power CF = .987 Efficiency CF = .995
4. Estimate Power and Efficiency Correction Factors for Exhaust Back Pressure	Use Table 7-4	for 3 inch WC: Power CF = .988 Efficiency CF = .993
5. Calculate Nominal Net Power Output	kW (net) = kW (step 2) X Inlet CF X Exhaust CF	For Example Above: kWnet = 172 kW
6. Calculate Nominal Net Efficiency	Efficiency (net) = Efficiency (step 1) X Inlet CF X Exhaust CF	For Example Above: Efficiency (net) = 31.3%
7. Calculate Fuel Input	Fuel [kW] = kW(net)/ Efficiency (net)	For Example Above: Fuel [kW] = 550 kW (or 1,880,000 BTU/hr)
8. Consider Parasitic Loads	Subtract parasitic loads, if any	For Low Pressure NG: Parasitic = 10 kW Useable Power = 162 kW
9. Estimate Exhaust Characteristics	Temp = Temp from step 1 Flow = Flow from step 1 times kWnet/kW step 2 less .5% per 1,000 ft Elevation	Exhaust Temp = 570°F Exhaust Flow = 2.7 lbm/s

Consider Tolerances

The calculations described above provide a relatively simple method to estimate electrical output, fuel consumption, and exhaust characteristics for given operating conditions. These calculations are based on nominal values, and do not consider differences from microturbine to microturbine or the measurement inaccuracies for each of the key parameters. The Capstone C200 Product Specification (460045) provides curves showing minimum and maximum expected power and efficiency at sea level. A similar tolerance range of outputs can be expected for the impact of altitude and pressures. The following sections call out a suggested approach to using the performance information in this section.

Grid Connect Applications

When operating connected to a utility grid, Capstone microturbines will always attempt to provide the set power demand. In the case where the set power demand is greater than what the microturbine is able to produce, the microturbine will provide the maximum that it can, given the specific operating conditions. This actual output may be above or below the nominal calculations defined above for that specific operating condition. For purposes of making economic projections, it is suggested that the nominal output be used, since this is what would be expected on average for a fleet of microturbines.

Note that the C200 operating in Grid Connect mode will generate real power (kW) at essentially unity power factor. This means that the apparent power (kVA) is equal to the real power (kW), and no reactive power is either provided to or taken from the utility grid.

Stand Alone Applications

Stand alone applications are more complicated than Grid Connect because only the microturbines are being relied upon for load power. Each microturbine will try to maintain its pre-set voltage, regardless of the connected loads. If the load is above the capability of the engine to provide continuous power, the batteries in the microturbine will supply the shortfall in an attempt to keep the system running. If this overload condition continues, the batteries will ultimately be drained and the system will eventually shut down. It is therefore suggested that steady state loads be sized based on the following steps:

1. Worst Case Operating Environment – For a given site location, “nominal” power should be estimated based on the actual elevation, highest expected ambient temperature, and any other de-rating considerations such as for inlet pressure loss or exhaust back pressure and any parasitic loads.
2. Minimum Performance Band – To account for variation between microturbines, a minimum power band should be calculated by subtracting 10kW from Step 1.
3. Load Safety Margin – As would be normal practice for any Stand Alone prime mover, a reasonable amount of head room should be allocated to cover unexpected load increases and/or normal variation in load tolerances. Connected loads should therefore not be sized to exceed 85% of the minimum performance band from Step 2.

In Stand Alone mode, the C200 microturbine provides voltage and is able to generate real power (kW) according to the calculations above, as well as provide reactive power (kVAR) that the connected loads may require. The C200 microturbine will try to provide total apparent power (kVA) up to the 310 Arms current limits of the power electronics. However, for design purposes, the power factor for the connected loads should not be less than .80 leading or lagging. Table 7-6 shows the respective maximum steady state currents at ISO conditions for different voltages.

Table 7-6. Maximum kVA and Current vs Voltage at ISO Conditions

System Voltage	Real Power	Power Factor	Apparent Power	Maximum Steady State Current
480 V line-to-line	200 kW	.78 (1)	258 kVA	310 Arms
400 V line-to-line	200 kW	.93 (1)	215 kVA	310 Arms

Note:

(1) Current is limited by power electronics capability, and power factor is limited by maximum current

ISO Partial Load Performance

Performance at partial load and ISO conditions for the Capstone C200 high pressure natural gas model is presented in Table 7-7. These values are estimated from nominal performance curves. Performance for biogas models is also predicted using Table 7-7, but biogas models are not designed to operate below 100kW net power output. Performance of the low pressure natural gas models can be estimated from Table 7-7 by first accounting for the parasitic loss of the compressor. As previously indicated, parameters such as exhaust temperature, exhaust mass flow, and fuel flow energy rate are determined prior to the deduction of the compressor's parasitic load. Therefore, for a given net output power, these performance characteristics can be estimated by using the performance values corresponding to the net output power plus 10kW.

Table 7-7. Partial Load Performance at ISO Ambient Conditions

Net Power (kW)	Net Efficiency (%)	Exhaust Temp (°F)	Exhaust Mass Flow Rate (lbm/s)	Exhaust Energy Rate (kW LHV)	Fuel Flow Energy Rate (Btu/hr LHV)	Net Heat Rate (Btu/kWh LHV)
15	13.6	326.7	0.97	69.8	375,455	25,030
16	14.2	328.4	0.99	71.4	384,351	24,022
17	14.8	330.1	1.00	73.0	392,872	23,110
18	15.3	331.9	1.02	74.7	402,481	22,360
19	15.8	333.6	1.03	76.5	412,009	21,685
20	16.2	335.3	1.05	78.2	421,460	21,073
21	16.7	337.0	1.07	79.9	430,836	20,516
22	17.1	338.6	1.08	81.6	440,141	20,006
23	17.5	340.2	1.10	83.3	449,378	19,538
24	17.9	341.8	1.11	84.9	458,550	19,106
25	18.3	343.3	1.13	86.6	467,658	18,706
26	18.6	344.8	1.14	88.2	476,706	18,335
27	19.1	346.1	1.15	89.6	484,231	17,934
28	19.4	347.6	1.17	91.2	493,451	17,623
29	19.7	349.0	1.18	92.9	502,626	17,332
30	20.0	350.5	1.20	94.5	511,758	17,059
31	20.3	351.9	1.21	96.2	520,866	16,802
32	20.6	353.3	1.23	97.8	529,932	16,560
33	20.9	354.6	1.24	99.4	538,959	16,332
34	21.2	356.0	1.26	101.1	547,946	16,116
35	21.5	357.3	1.27	102.7	556,887	15,911
36	21.8	358.6	1.28	104.3	565,771	15,716
37	22.0	359.8	1.30	105.9	574,617	15,530
38	22.3	361.1	1.31	107.4	583,426	15,353
39	22.5	362.3	1.32	109.0	592,198	15,185
40	22.8	363.5	1.34	110.6	600,935	15,023
41	23.0	364.7	1.35	112.1	609,639	14,869

Continued on next page

Net Power (kW)	Net Efficiency (%)	Exhaust Temp (°F)	Exhaust Mass Flow Rate (lbm/s)	Exhaust Energy Rate (kW LHV)	Fuel Flow Energy Rate (Btu/hr LHV)	Net Heat Rate (Btu/kWh LHV)
42	23.2	365.8	1.36	113.7	618,309	14,722
43	23.4	367.0	1.38	115.2	626,948	14,580
44	23.7	368.1	1.39	116.8	635,555	14,444
45	23.9	369.2	1.40	118.2	643,615	14,303
46	24.1	370.3	1.41	119.7	652,323	14,181
47	24.3	371.6	1.43	121.3	661,013	14,064
48	24.5	372.9	1.44	122.8	669,679	13,952
49	24.7	374.2	1.45	124.4	678,323	13,843
50	24.9	375.4	1.46	125.9	686,950	13,739
51	25.1	376.7	1.47	127.4	695,586	13,639
52	25.2	377.9	1.48	129.0	704,194	13,542
53	25.4	379.1	1.50	130.5	712,777	13,449
54	25.6	380.3	1.51	132.0	721,335	13,358
55	25.8	381.4	1.52	133.5	729,869	13,270
56	25.9	382.6	1.53	135.0	738,381	13,185
57	26.1	383.6	1.54	136.4	745,739	13,083
58	26.3	384.8	1.55	137.9	754,460	13,008
59	26.4	386.0	1.56	139.5	763,213	12,936
60	26.6	387.2	1.57	141.1	771,953	12,866
61	26.7	388.4	1.58	142.6	780,681	12,798
62	26.9	389.6	1.60	144.2	789,396	12,732
63	27.0	390.7	1.61	145.8	798,098	12,668
64	27.1	391.9	1.62	147.3	806,788	12,606
65	27.3	393.0	1.63	148.9	815,465	12,546
66	27.4	394.1	1.64	150.5	824,234	12,488
67	27.5	395.2	1.65	152.0	832,781	12,430
68	27.6	396.3	1.66	153.6	841,419	12,374
69	27.8	397.4	1.67	155.1	850,044	12,319
70	27.9	398.5	1.68	156.7	858,657	12,267
71	28.0	399.6	1.70	158.2	867,256	12,215
72	28.1	400.6	1.71	159.8	875,842	12,164
73	28.2	401.7	1.72	161.3	884,416	12,115
74	28.3	402.7	1.73	162.9	892,977	12,067
75	28.4	403.7	1.74	164.4	901,525	12,020
76	28.5	404.8	1.75	165.9	910,060	11,974
77	28.7	405.8	1.76	167.5	918,582	11,930
78	28.8	406.8	1.77	169.0	927,091	11,886
79	28.9	407.8	1.78	170.5	935,588	11,843
80	29.0	408.7	1.79	172.0	944,072	11,801
81	29.1	409.7	1.80	173.5	952,385	11,758

Continued on next page

Net Power (kW)	Net Efficiency (%)	Exhaust Temp (°F)	Exhaust Mass Flow Rate (lbm/s)	Exhaust Energy Rate (kW LHV)	Fuel Flow Energy Rate (Btu/hr LHV)	Net Heat Rate (Btu/kWh LHV)
82	29.2	410.7	1.81	175.1	960,913	11,718
83	29.3	411.6	1.82	176.6	969,427	11,680
84	29.4	412.6	1.83	178.1	977,927	11,642
85	29.5	413.5	1.84	179.6	986,413	11,605
86	29.5	414.4	1.85	181.2	994,885	11,568
87	29.6	415.4	1.86	182.7	1,003,343	11,533
88	29.7	416.3	1.87	184.2	1,011,811	11,498
89	29.8	417.2	1.88	185.7	1,020,294	11,464
90	29.9	418.2	1.89	187.3	1,028,766	11,431
91	30.0	419.1	1.90	188.8	1,037,228	11,398
92	30.1	420.0	1.91	190.3	1,045,679	11,366
93	30.2	420.9	1.92	191.8	1,054,119	11,335
94	30.2	421.7	1.93	193.3	1,062,549	11,304
95	30.3	422.5	1.94	194.7	1,069,985	11,263
96	30.4	423.4	1.95	196.2	1,078,433	11,234
97	30.5	424.3	1.96	197.7	1,086,877	11,205
98	30.6	425.1	1.97	199.2	1,095,309	11,177
99	30.7	426.0	1.98	200.7	1,103,683	11,148
100	30.7	426.8	1.99	202.2	1,112,057	11,121
101	30.8	427.6	2.00	203.7	1,120,432	11,093
102	30.9	428.4	2.01	205.2	1,128,807	11,067
103	31.0	429.2	2.02	206.7	1,137,183	11,041
104	31.0	430.0	2.03	208.2	1,145,561	11,015
105	31.1	430.8	2.04	209.7	1,153,940	10,990
106	31.2	431.6	2.05	211.2	1,162,321	10,965
107	31.2	432.4	2.06	212.7	1,170,703	10,941
108	31.3	433.2	2.07	214.2	1,179,088	10,917
109	31.4	433.9	2.08	215.7	1,187,485	10,894
110	31.4	434.7	2.09	217.2	1,195,881	10,872
111	31.5	435.5	2.10	218.7	1,204,276	10,849
112	31.6	436.3	2.11	220.3	1,212,669	10,827
113	31.6	432.7	2.12	219.1	1,221,060	10,806
114	31.7	433.8	2.13	220.8	1,229,451	10,785
115	31.7	434.9	2.14	222.5	1,237,861	10,764
116	31.8	436.0	2.15	224.3	1,246,337	10,744
117	31.9	437.2	2.16	226.0	1,254,962	10,726
118	31.9	438.3	2.17	227.8	1,263,920	10,711
119	31.9	439.4	2.18	229.6	1,273,180	10,699
120	32.0	440.5	2.19	231.4	1,282,448	10,687
121	32.0	441.7	2.20	233.2	1,291,725	10,675

Continued on next page

Net Power (kW)	Net Efficiency (%)	Exhaust Temp (°F)	Exhaust Mass Flow Rate (lbm/s)	Exhaust Energy Rate (kW LHV)	Fuel Flow Energy Rate (Btu/hr LHV)	Net Heat Rate (Btu/kWh LHV)
122	32.0	442.8	2.21	235.0	1,301,011	10,664
123	32.1	443.9	2.22	236.8	1,310,306	10,653
124	32.1	445.0	2.23	238.5	1,319,452	10,641
125	32.1	446.1	2.24	240.3	1,328,760	10,630
126	32.2	447.2	2.25	242.2	1,338,080	10,620
127	32.2	448.3	2.26	244.0	1,347,412	10,610
128	32.2	449.4	2.27	245.8	1,356,757	10,600
129	32.3	450.5	2.28	247.6	1,366,114	10,590
130	32.3	451.6	2.29	249.4	1,375,483	10,581
131	32.3	452.7	2.30	251.3	1,384,866	10,571
132	32.3	453.8	2.31	253.1	1,394,263	10,563
133	32.4	454.9	2.32	255.0	1,403,673	10,554
134	32.4	456.0	2.33	256.8	1,412,997	10,545
135	32.4	457.1	2.34	258.6	1,422,226	10,535
136	32.5	458.3	2.35	260.4	1,431,464	10,525
137	32.5	459.4	2.35	262.2	1,440,713	10,516
138	32.5	460.6	2.36	264.0	1,449,971	10,507
139	32.5	461.8	2.37	265.8	1,459,240	10,498
140	32.6	462.9	2.38	267.6	1,468,174	10,487
141	32.6	464.1	2.39	269.5	1,477,702	10,480
142	32.6	465.3	2.40	271.4	1,487,248	10,474
143	32.6	466.5	2.41	273.3	1,496,813	10,467
144	32.6	467.7	2.42	275.2	1,506,395	10,461
145	32.7	468.9	2.43	277.1	1,515,997	10,455
146	32.7	470.1	2.43	279.0	1,525,618	10,449
147	32.7	471.3	2.44	280.9	1,535,259	10,444
148	32.7	472.4	2.45	282.9	1,544,919	10,439
149	32.7	473.6	2.46	284.8	1,554,601	10,434
150	32.7	474.8	2.47	286.8	1,564,303	10,429
151	32.8	476.0	2.48	288.7	1,574,027	10,424
152	32.8	477.2	2.49	290.7	1,583,773	10,420
153	32.8	478.4	2.50	292.7	1,593,542	10,415
154	32.8	479.6	2.51	294.6	1,603,333	10,411
155	32.8	480.8	2.52	296.6	1,613,148	10,407
156	32.8	482.0	2.53	298.6	1,622,986	10,404
157	32.8	483.2	2.53	300.6	1,632,849	10,400
158	32.8	484.4	2.54	302.7	1,642,738	10,397
159	32.8	485.6	2.55	304.7	1,652,651	10,394
160	32.8	486.8	2.56	306.7	1,662,591	10,391

Continued on next page

Net Power (kW)	Net Efficiency (%)	Exhaust Temp (°F)	Exhaust Mass Flow Rate (lbm/s)	Exhaust Energy Rate (kW LHV)	Fuel Flow Energy Rate (Btu/hr LHV)	Net Heat Rate (Btu/kWh LHV)
161	32.9	488.0	2.57	308.8	1,672,558	10,389
162	32.9	489.1	2.58	310.8	1,682,552	10,386
163	32.9	490.3	2.59	312.9	1,692,574	10,384
164	32.9	491.5	2.60	314.9	1,702,625	10,382
165	32.9	492.7	2.61	317.0	1,712,704	10,380
166	32.9	494.0	2.62	319.2	1,722,814	10,378
167	32.9	495.3	2.63	321.4	1,733,206	10,378
168	32.9	496.5	2.64	323.5	1,743,439	10,378
169	32.9	497.7	2.65	325.6	1,753,592	10,376
170	32.9	499.0	2.65	327.8	1,763,765	10,375
171	32.9	500.2	2.66	329.9	1,773,957	10,374
172	32.9	501.4	2.67	332.0	1,784,170	10,373
173	32.9	502.6	2.68	334.1	1,794,402	10,372
174	32.9	503.8	2.69	336.3	1,804,654	10,372
175	32.9	505.0	2.70	338.4	1,814,926	10,371
176	32.9	506.2	2.71	340.6	1,825,218	10,371
177	32.9	507.4	2.72	342.8	1,835,529	10,370
178	32.9	508.6	2.73	344.9	1,845,860	10,370
179	32.9	509.8	2.74	347.1	1,856,210	10,370
180	32.9	511.1	2.75	349.3	1,866,580	10,370
181	32.9	512.3	2.76	351.5	1,876,969	10,370
182	32.9	513.5	2.76	353.7	1,887,377	10,370
183	32.9	514.7	2.77	355.9	1,897,805	10,371
184	32.9	515.9	2.78	358.1	1,908,251	10,371
185	32.9	517.1	2.79	360.3	1,918,716	10,371
186	32.9	518.3	2.80	362.6	1,929,204	10,372
187	32.9	519.5	2.81	364.8	1,939,729	10,373
188	32.9	520.7	2.82	367.1	1,950,365	10,374
189	32.9	521.9	2.83	369.3	1,961,043	10,376
190	32.9	523.1	2.84	371.6	1,971,739	10,378
191	32.9	524.3	2.85	373.9	1,982,454	10,379
192	32.8	525.6	2.86	376.3	1,993,337	10,382
193	32.8	526.8	2.87	378.6	2,004,228	10,385
194	32.8	528.1	2.88	381.0	2,015,127	10,387
195	32.8	529.3	2.89	383.3	2,026,034	10,390
196	32.8	530.6	2.89	385.7	2,036,945	10,393
197	32.8	531.8	2.90	388.0	2,047,861	10,395
198	32.8	533.0	2.91	390.4	2,058,779	10,398
199	32.8	534.2	2.92	392.8	2,069,697	10,400
200	32.8	535.1	2.93	394.6	2,078,942	10,395

ISO partial load efficiency vs. net power for the C200 high pressure natural gas model is shown in Figure 7-3. These values are estimated from nominal performance at ISO conditions.

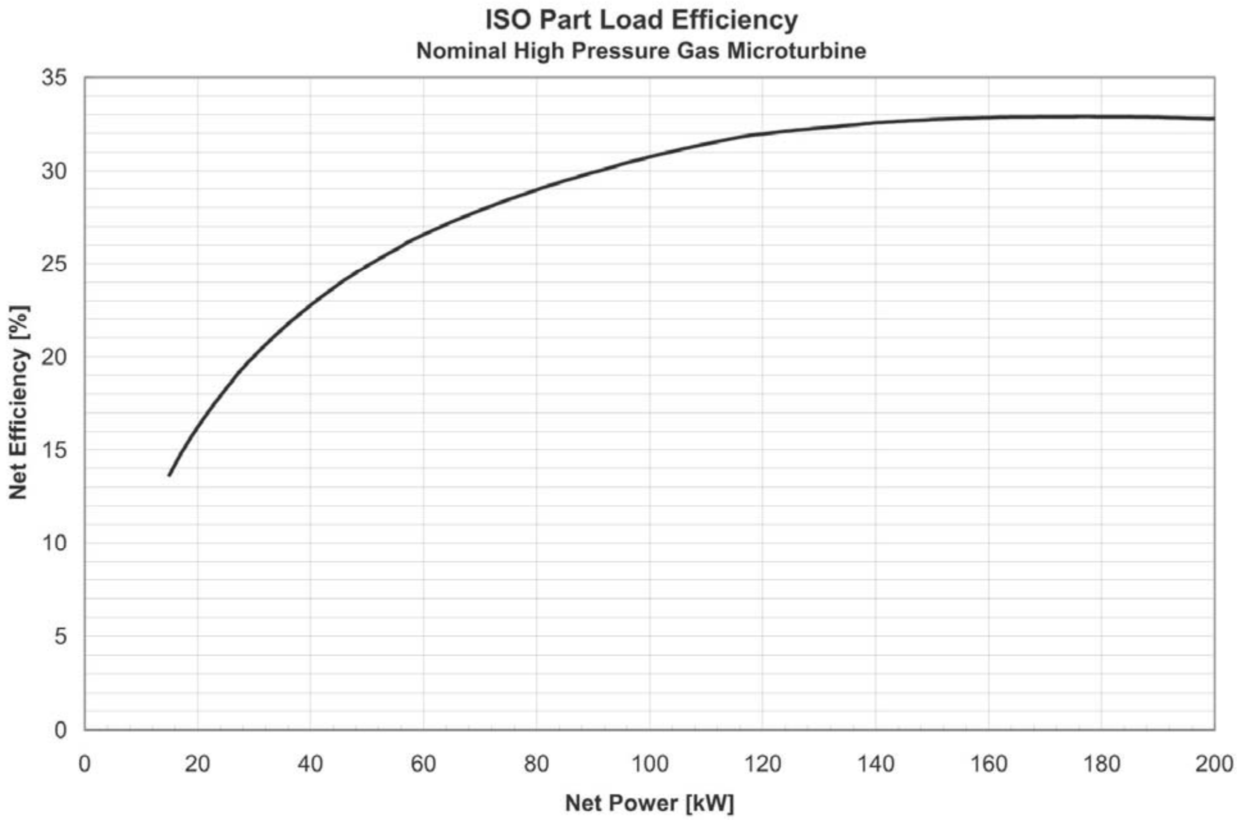


Figure 7-3. ISO Partial Load Efficiency Vs Net Power (Nominal)

CHAPTER 8: ELECTRICAL RATINGS

The purpose of this section is to define the electrical output ratings of the Capstone C200 microturbine in both single unit and MultiPac arrangements. This information is intended for use in evaluating applications for the Capstone C200 microturbine.

The single unit and the MultiPac electrical ratings are dependent upon the operating mode selected; that is, Grid Connect or Stand Alone. In a MultiPac, microturbines can be installed in groups of up to 20 units (more with the optional Capstone Advanced Power Server) to operate as a single power generation source.

Grid Connect

Table 8-1 presents the Electrical Ratings for the Grid Connect configuration. Whenever an expression is listed, N equals the number of individual microturbines within a MultiPac (N can be up to 20 if a C200 is the MultiPac Master, or more if the Capstone Advanced Power Server is acting as the MultiPac Master).

Table 8-1. Electrical Ratings: Grid Connect

Description	Single Unit	MultiPac
Grid Voltage Operating Range	352 to 528 VAC, (3-phase only)	Same as Single Unit
Output Voltage Connection	4 wire, L1, L2, L3 and neutral	Same as Single Unit
Maximum Grid Impedance	≤ 10% inductive (298 μH) ≤ 5% resistive (56 mOhms), Z_{base}= 1.12 ohms line-to-neutral	≤ 10% inductive (298/N μH) ≤ 5% resistive (56/N mOhms), Z_{base}= 1.12/N ohms line-to-neutral
Grid Voltage Harmonic Distortion	The grid must comply with IEEE 519. (Note 1).	Same as Single Unit
Grid Voltage Balance	Within ± 2% at full load	Same as Single Unit
Grid Voltage Phase Displacement	120 (± 1) degrees	Same as Single Unit
Grid Voltage Phase Rotation	Either clockwise or counter-clockwise. Auto synchronization. For Dual Mode applications, the grid voltage phase rotation must be L1, L2, L3 counter-clockwise	Same as Single Unit
Grid Inrush Current @ Disconnect Switch Closure	<15 Amps RMS	<(N*15) Amps RMS

Continued on next page

Description	Single Unit	MultiPac
Grid Frequency Acquisition Range	45 - 65 Hz. Auto synchronization. The microturbine senses the grid waveform and synchronizes to its phases and frequency before an output connection is made.	Same as Single Unit
Nominal Real Power Output @ ISO (Note 2)	0 to 200 kW HP NG 0 to 190 kW LP NG 75 to 200 kW HP Landfill Gas 75 to 200 kW HP Digester Gas	kW = N * kW_{MT}
Apparent Power Output @ ISO	kVA_{MT} = kW_{MT} (above)	kVA = N * kVA_{MT}
Output Power Factor to Grid	± 0.985 displacement PF, for loads > 25% of rated load	Same as Single Unit
Typical Output Power Slew Rate	± 6 kW/second, for natural gas; ± 2kW/sec for Landfill/Digester Gas	± N*Single Unit kW/second
Maximum Output Current (Note 3)	230 Amps RMS @ 480V LP NG 240 Amps RMS @ 480 V all others 275 Amps RMS @ 400 V LP NG 290 Amps RMS @ 400 V all others	N*Single Unit Amps RMS
Output Current Harmonic Content	Complies with IEEE 519, UL1741: < 5% THD. See Figure 8-1.	Same as Single Unit
Output Current DC Content	<0.5% (1.4 Amps) DC (per UL 1741)	< N*1.4 Amps DC (UL 1741)
Grid Fault Current Contribution by microturbine	500 Amps RMS, maximum symmetrical and asymmetrical	N*500 Amps RMS, maximum symmetrical and asymmetrical
Power Required @ Start Command	20 kW peak, 0.13 kW-Hr, 70 Seconds	kW = N*single unit Time same as single unit
Cooldown Power (Note 4)	No net utility power 300 seconds	kW = N*single unit Time same as single unit
Draw in Standby Power	.30 kW	N*.30 kW
Grounding (Note 5)	Grid must be Neutral grounded.	Same as Single Unit
Surge Voltage Withstand	± 6 kV (ANSI 62.41)	Same as Single Unit
Short Circuit Rating	Per UL 508C, the microturbine is not short circuit rated (Note 6)	Same as Single Unit

Notes:

(1) Total harmonic voltage must be less than 5% (13.9 VRMS line-to-neutral for a 480 V system). Also, the high frequency ripple voltage must be less than 2% (5.5 VRMS line-to-neutral for a 480 V system) at frequencies greater than 3 kHz.

(2) Refer Chapter 7: Performance for real power capability as a function of ambient temperature, elevation, and other site conditions.

(3) The maximum currents are limited by the real power capability of the microturbine. Values listed are for full power at ISO conditions. Refer to Chapter 7: Performance for real power capability as a function of ambient temperature, elevation, and other site conditions.

(4) Any load connected to the auxiliary contactor is in addition to the motoring loads shown in order to keep the microturbine in cooldown.

(5) Refer to Chapter 12: Installation for additional details.

(6) UL 1741 test-rated short circuit is 500 A_{RMS}.

Figure 8-1 presents the typical Total Harmonic Current as a function of load for one Capstone C200 microturbine of a MultiPac in the Grid Connect mode.

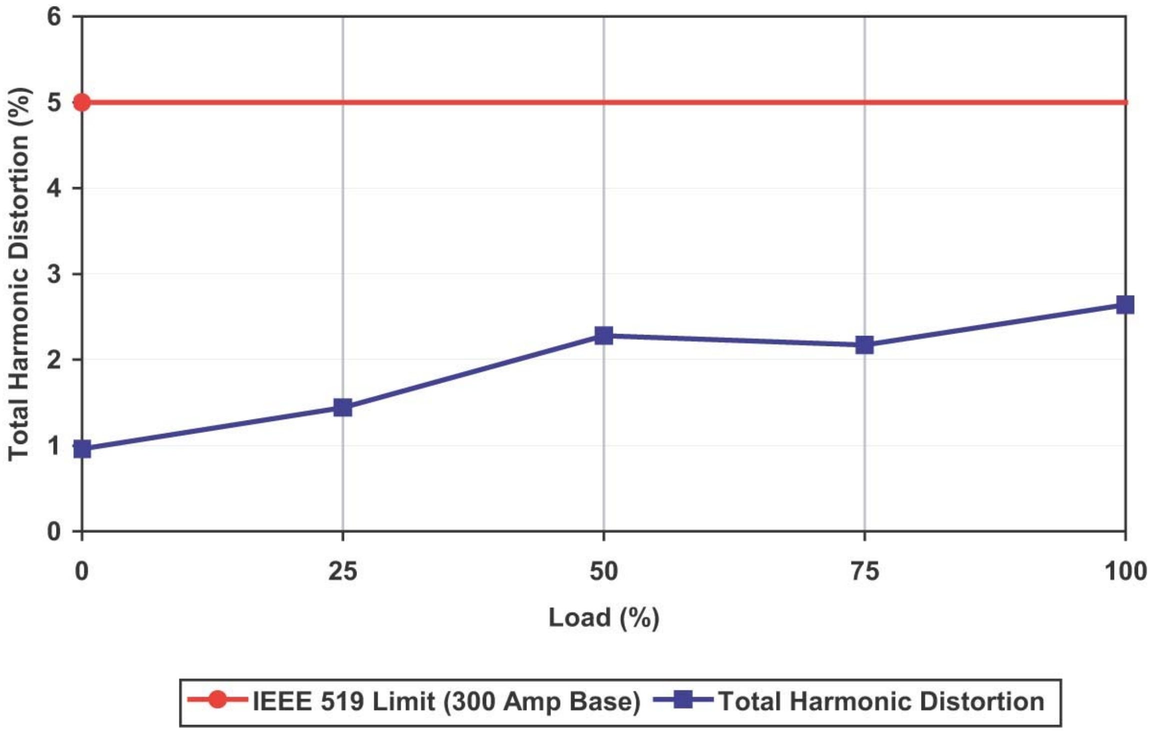


Figure 8-1. Typical Total Harmonic Current

Stand Alone

Table 8-2 presents the Electrical Ratings for the Stand Alone mode of operation. Whenever an expression is listed, N equals the number of individual microturbines within a MultiPac (N can be up to 20 if a C200 is the MultiPac Master, or more if the Capstone Advanced Power Server is acting as the MultiPac Master).

Table 8-2. Electrical Ratings: Stand Alone

Description	Single Unit	MultiPac
Output Voltage Adjustment Range	150 to 480 VAC line-to-line (1 VAC adjustment resolution)	Same as Single Unit
Output Voltage Accuracy	± 2% of reading, (± 1% typical) line-to-neutral	Same as Single Unit
Output Voltage Stability, Time	± 1.5% per 40,000 hours	Same as Single Unit
Output Voltage Stability, Temperature	± 0.2% over −20 to +50 °C (ambient temperature)	Same as Single Unit
Output Voltage Configuration	3-Phase, 4 wire, L1, L2, L3, and N	Same as Single Unit
Nominal Real Power Output @ ISO (Note 1)	0 to 200 kW HP NG 0 to 190 kW LP NG	$kW = kW_{MT} * N$
Maximum Output kVA @ ISO (Note 2)	258 kVA @ 480 V 215 kVA @ 400 V	N * Single Unit
Load Power Factor Range (Note 2)	0.8 lagging (inductive) to 0.8 leading (capacitive)	Same as Single Unit
Output Voltage Harmonic Distortion, with Linear Load	≤ 5% THD: complies with IEEE 519.	Same as Single Unit
Output Voltage Harmonic Distortion, with CF load. Crest Factor (CF) = I_{PEAK} / I_{RMS}	< 8% THD, $I_{PEAK} \leq$ 675 Amps $1.4 \leq CF \leq 3.0$	< 8% THD, $I_{PEAK} \leq$ *N*675 Amps $1.4 \leq CF \leq 3.0$
Output DC Voltage Content	± 2.5 VDC line-to-neutral	Same as Single Unit
Output Voltage Step Load Regulation, load application or removal	< ± 20% of nominal voltage for any resistive step load ≤ 75% rated load	Same as Single Unit
Output Voltage Step Load Recovery Time	< 100 milliseconds to within ± 5% of nominal voltage for ≤ 75% rated load step	Same as Single Unit

Continued on next page

Notes:

(1) Refer to Chapter 7: Performance for real power capability as a function of ambient temperature, elevation, and other site conditions. Additional considerations for worst case operating environment, minimum tolerance band, and load safety margin need to be taken into account when designing a system for Stand Alone operation, so the maximum figures shown above should only be used as a reference.

(2) Values shown are limited by maximum current capability of the power electronics. For system design, total power factor for all connected loads should not be less than 0.8 (inductive or capacitive).

Description	Single Unit	MultiPac
Output Voltage Phase Displacement	120 (± 1) degree @ balanced loads	Same as Single Unit
Output Voltage Phase Displacement Jitter	± 1 degree @ balanced loads	Same as Single Unit
Output Voltage Phase Rotation	L1, L2, L3 counter-clockwise	Same as Single Unit
Output Frequency Adjustment Range	45 - 65 Hz (0.1Hz adjustment resolution), ± 0.05% accuracy. For integer frequency settings, the accuracy is +/- 0.005%.	Same as Single Unit
Output Frequency Regulation	0% change for any steady state load or transient load ≤ 75%	Same as Single Unit
Output Frequency Stability, Time	± 0.0005% per year	Same as Single Unit
Output Frequency Stability, Temperature	± 0.005%, -20 to +50 °C	Same as Single Unit
Maximum Continuous Output Current (Note 3)	310 Amps RMS	Amps RMS = N * 310
Output Load Crest Factor	2.18 maximum @ 310 Amps RMS $CF=675/I_{RMS}$ for loads < 310 Amps RMS	2.18 maximum @ Amps RMS = 310*N $CF=N*675/I_{RMS}$ for loads < 310*N Amps RMS
Output Instantaneous Load Current	675 Amps peak, maximum	N*675 Amps peak, maximum
Overload Capacity (% of full rated power output)	150%, 10 seconds; 125%, 30 seconds; 110% 60 seconds (Note 4)	N * Single Unit
Output Fault Current	500 Amps RMS, maximum symmetrical and asymmetrical	N*500 Amps RMS, maximum symmetrical and asymmetrical

Continued on next page

Notes:

(3) The maximum steady state current is limited by the capability of the power electronics, and may be further restricted by the output capability of the microturbine. Refer to Chapter 7: Performance for real and apparent power capability as a function of ambient temperature, elevation, and other site conditions.

(4) Values are for battery state of charge >70%. Note that overload capacity depends on the maximum real output power capability of the system. Refer to Chapter 7: Performance for real and apparent power capability as a function of ambient temperature, elevation, and other site conditions.

Description	Single Unit	MultiPac
Single Phase Loading (per individual microturbine within the MultiPac)	80 kW line-to-neutral maximum steady state	N*80kW line-to-neutral maximum steady state
Load Unbalance among the 3-phases (per individual unit within the MultiPac)	80 kW maximum. A typical arrangement of unbalanced loads is 90 kW, 10 kW, and 10 kW per phase, per unit, respectively (for example).	Same as Single Unit
Surge Voltage Withstand	± 6 kV (ANSI 62.41)	Same as Single Unit
Grounding (Note 5)	Neutral must be solidly connected to earth ground in a single location.	Same as Single Unit
Motor Start, Across-the-line	Motor inrush current < 475 Amps RMS. This current limit must not be exceeded at any time during acceleration to full speed.	Motor inrush current < N*475 Amps RMS. This current limit must not be exceeded at any time during acceleration to full speed.
Motor Start, Ramp Voltage and Frequency	475 Amps RMS: maximum starting current at any frequency and voltage. This current limit must not be exceeded at any time during acceleration to full speed.	N*475 Amps RMS, maximum starting current at any frequency and voltage. This current limit must not be exceeded at any time during acceleration to full speed.

Note:

(5) Refer to **Chapter 12: Installation** for additional details.

Figure 8-2 presents the typical output voltage (Line-to-Line) Total Harmonic Distortion (THD) as a function of Linear Resistive Load for the Capstone C200 microturbine.

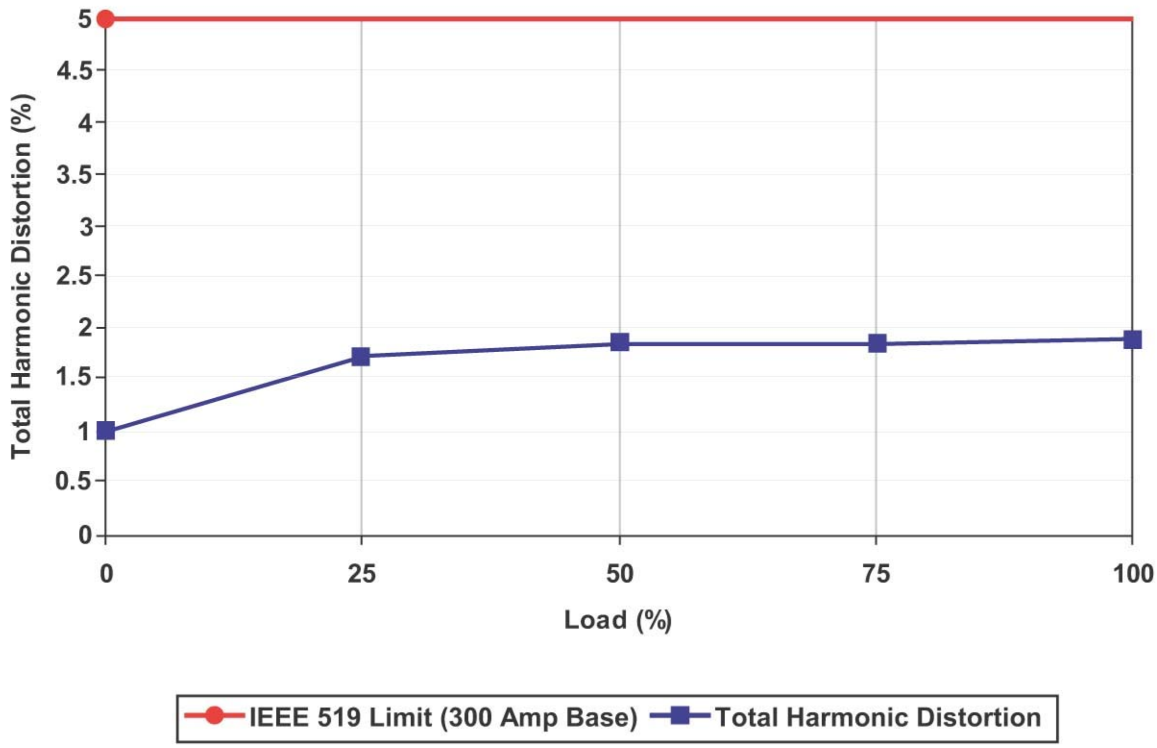


Figure 8-2. Typical Output Voltage Total Harmonic Distortion

Auxiliary Output

Introduction

This auxiliary contactor is a small AC power output connection that is available in the Power Connection Bay. Its purpose is to supply AC output power of the same type as the primary output power to critical loads prior to the primary load being energized. This power can be used to enable control systems, pumps for water systems, heating systems, or any other systems that need to be active for a certain amount of time before and after the load is enabled.

Capacity

The auxiliary AC power output is not an independent power source from the primary AC power output, however it is an independently switched output. This means that the capacity of the system AC output equals the sum of the outputs of the main and auxiliary output. The auxiliary output is capable of delivering up to 10kVA.

Timing

The auxiliary AC power output is energized once the system reaches the run state and stays energized until the shutdown, fault or restart states are reached. Additionally, a manual command and a discrete input control are available. These control the transition from the run state to the load state and allow the user the ability to control the timing between the auxiliary output contactor and the main output contactor closing. This timing control is also available in the form of a user settable timer for the routine shutdown transition from cooldown to the shutdown state. These various inputs and timers allow the user to customize the auxiliary output power for his particular site needs.

Measurement Accuracy

The displays of the output voltages, currents, frequencies, and power have typical accuracies and coefficients as presented in Table 8-3.

Table 8-3. Typical/Maximum Instrumentation Accuracy and Coefficients

Instrumentation Item	Accuracy and Coefficients (Typical/Maximum)
Current	±1.5% of Full Scale (typical) / ±3.0% (maximum)
Current Temperature Coefficient	± 0.2% of Full Scale over –20 to +50 °C range
Voltage	± 1.0% of Full Scale (typical) /±2.0% (maximum)
Voltage Temperature Coefficient	± 0.2% of Full Scale over –20 to +50 °C range
Output Power	± 2.5% of Full Scale (typical) /± 5.0%(maximum)
Output Power Temperature Coefficient	± 0.4% of Full Scale over –20 to +50 °C range
Output Frequency	± 0.05% of Reading (or Indication)
Output Frequency Temperature Coefficient	± 0.005% of Reading over –20 to +50 °C range
Real Time Clock	±1 minute per month

CHAPTER 9: PROTECTIVE RELAY FUNCTIONS

Introduction

The Capstone microturbine generator may be connected in parallel to a utility grid to power local Grid Connected loads. When installed in this fashion, power generated by the microturbine is supplied to these loads only when the utility grid voltage is present. Utilities commonly require that protective relay devices be installed with generators connected to their grid. The primary purpose of these devices is to ensure that the local generator will not energize utility wires de-energized by the utility. Typically, these protective relay devices are dedicated relays or solid-state power analyzers that provide control signals to disconnecting devices. This document presents information for the protective relay functions incorporated into Capstone microturbines.

The C200 microturbine has built in protective relay functions. Programmable settings for the protective relay functions are stored in nonvolatile memory within the microturbine. As a result, any changes remain set even after an interruption in utility power. Detailed information on how to set these protective functions is provided in the C200 microturbine User's Manual (400008) and CRMS Technical Reference User's Edition (410013).

During utility grid voltage interruptions, the microturbine senses the loss of utility voltage and disconnects from the grid and the local loads. When the grid voltage returns to within its specified limits, the microturbine may be programmed to restart and supply power to the connected loads. Figure 9-1 shows the relationship between the microturbine, local loads and the utility grid.

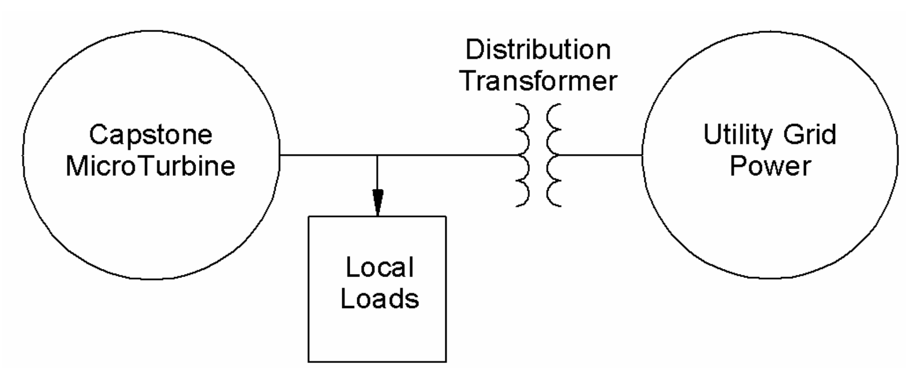


Figure 9-1. Grid Connect System Configuration

Protective Functions

The protective functions included in the C200 microturbine are described in this section. Voltage sensing and signal processing are described in the System Overview section. The Protective Function designator numbers correspond to those published by IEEE[1].

NOTE	All protective function measurements and calculations are based on the Line-to-Neutral voltage values. However, for convenience, all protective function settings are entered as equivalent Line-to-Line voltage values.

When a protective function initiates a shutdown, the following occurs:

1. Output power flow ceases within one millisecond for at least four milliseconds
2. The main power output contactor is opened within 100 milliseconds.
3. Fuel flow to the microturbine stops, and
4. A warm shutdown is initiated, during which control power is supplied from the microturbine generator as it slows down. The warmdown lasts 1 – 2 minutes before the rotor is stopped.

Under Voltage (Protective Function 27)

Primary Under Voltage Trip

The Primary Under Voltage is adjustable from 352 V_{L-L} up to the Over Voltage set point. (Initial factory setting = 422 V). The time period is adjustable from 0.01 to 10.00 seconds in 0.01 second increments. (Initial factory setting = 2.00 seconds)

The UL1741 requirement for this function is:

- The device should cease to energize the output within 2 seconds when any of the phase voltages is lower than 244 V_{L-N} while the other phase voltages remain at 277 V_{L-N}

As shipped, each microturbine is tested to verify that it meets the UL1741 requirement to initiate a Grid Fault Shutdown, if any phase-to-neutral voltage sags to less than 244 V_{L-N} for duration greater than 2.0 seconds.

The primary trip voltage set point may be adjusted upwards within the range indicated in Table 9-1 and still comply with UL1741.

The primary duration to trip may also be adjusted downwards as indicated in Table 9-1 and still comply with UL1741.

Fast Under Voltage Trip

The Fast Under Voltage is adjustable from 0 V_{L-L} up to the Under Voltage set point. (Initial factory setting = 240 V_{L-L}). The time period is adjustable from 0.03 to 1.00 second in 0.01 second increments. (Initial factory setting = 0.16 seconds)

[1] IEEE C37.90-1989. IEEE Standard relays and Relay Systems Associated with Electric Power Apparatus. Institute of Electrical and Electronics Engineers, New York.

The UL1741 requirement for this function is:

- The device should cease to energize the output within 0.16 seconds when any of the phase voltages is lower than 139 V_{L-N} while the other phase voltages remain at 277 V_{L-N}

As shipped, each microturbine is tested to verify that it meets the UL1741 requirement to cease power export to the grid within 160 ms if the phase-to-neutral voltage drops to 139 V_{L-N}.

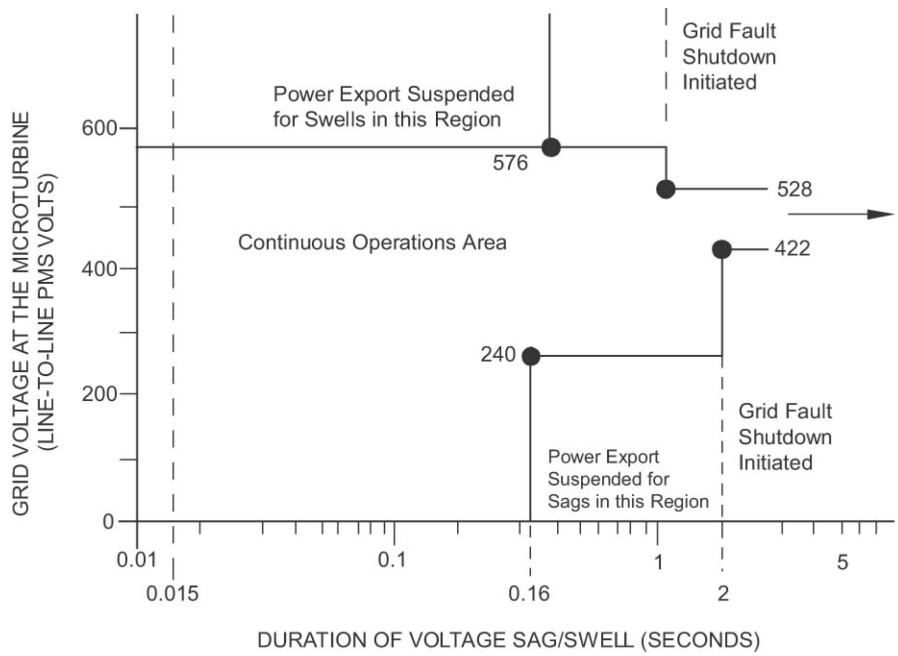
The Fast Under Voltage Trip level may be adjusted upwards as indicated in Table 9-1 and still comply with UL1741. The duration to the Fast Under Voltage Trip may also be adjusted downwards as indicated in Table 9-1 and still comply with UL1741.

The Under Voltage protective functions are illustrated in Figure 9-2. The under voltage trips are programmed into the microturbine as phase-to-phase voltages.

Voltages indicated in Figure 9-2 are phase-to-phase voltages. However, the actual trip functions are based on phase-to-neutral voltages with equivalent trip levels.

Table 9-1. Under Voltage Protective Function Parameters

Display Mode Grid Connect Menu	Parameter Description	Parameter Value	Initial Factory Setting	RS-232 Command to read the settings
Under Voltage	If the voltage on any phase falls below this setting for greater than Under Voltage Time, the system will shut down.	352 to Over Voltage (L-L)	422	UNDVLT
Under Voltage Time	Establishes the time period allowed for any phase voltage to fall below the Under Voltage limit.	0.01 to 10 seconds	2.00	UVLTTM
Fast Under Voltage	The system will cease to export power to the grid within 1 msec if any phase voltage drops below this voltage for greater than Fast Under Voltage Time.	0 to Under Voltage (L-L)	240	FSTUVL
Fast Under Voltage Time	Establishes the time period allowed for any phase voltage to fall below the Fast Under Voltage limit.	0.03 to 1.00 seconds	0.16	UVFSTM



Note: Trip voltages and durations shown in Figure 9-2 are those entered into the C200 microturbine prior to shipment. The Primary and Fast Over/Under Voltage trip levels and durations may be adjusted at installation as indicated in Table 9-1 and Table 9-2.

Figure 9-2. Grid Fault Shutdown Trip Limits for Over/Under Voltage Events

Over Voltage (Protective Function 59)

Primary Over Voltage Trip

The Primary Over Voltage is adjustable from 528 V_{L-L} down to the Under Voltage set point. (Initial factory setting = 528V). The time period is adjustable from 0.01 to 10.00 seconds in 0.01 second increments. (Initial factory setting = 1.00 seconds)

The UL1741 requirement for this function is:

- The device should cease to energize the output within 1 second when any of the phase voltages is higher than 305 V_{L-N} while the other phase voltages remain at 277 V_{L-N}

As shipped, each microturbine is tested to verify that it meets the UL1741 requirement to initiate a Grid Fault Shutdown if any phase voltage swells to greater than 305 VL-N for duration greater than 1.0 seconds. The primary trip voltage set point may be adjusted downwards within the range indicated in Table 9-2 and still comply with UL1741. The primary duration to trip may also be adjusted downwards as indicated in Table 9-2 and still comply with UL1741.

Fast Over Voltage Trip

The Fast Over Voltage is adjustable from the Over Voltage up to 634 V. (Initial factory setting = 576V). The time period is adjustable from 0.03 to 1.00 second in 0.01 second increments. (Initial factory setting = 0.16 seconds).

The UL1741 requirement for this function is:

- The device should cease to energize the output within 0.16 seconds when any of the phase voltages is higher than 333 V_{L-N} while the other phase voltages remain at 277 V_{L-N}

As shipped, each microturbine is tested to verify that it meets the UL1741 requirement to cease power export to the grid within 160 ms if any phase voltage swells to 333 V_{L-N}.

The Fast Over Voltage Trip level may be adjusted downwards as indicated in Table 9-2 and still comply with UL1741. The duration to Fast Over Voltage Trip may also be adjusted downwards as indicated in Table 9-2 and still comply with UL1741.

These Over Voltage protective functions are illustrated in Figure 9-2. The over voltage trips are programmed into the Power Controller as phase-to-phase voltages. Voltages indicated in Figure 9-2 are phase-to-phase voltages. However, the actual trip functions are based on phase-to-neutral voltages with equivalent trip levels.

Table 9-2. Over Voltage Protective Function Parameters

Display Mode / Grid Connect Menu	Parameter Description	Parameter Value	Initial Factory Settings	RS-232 Command to read the settings
Over Voltage	If the voltage on any phase rises above this setting for greater than Over Voltage Time, the system will shut down.	Under Voltage to 528 V (L-L)	528	OVRVLT
Over Voltage Time	Establishes the time period allowed for any phase voltage to rise above the Over Voltage limit.	0.01 to 10.00 seconds	1.00	OVLTTM
Fast Over Voltage	The system will cease to export power to the grid within 1 msec if any phase voltage rises above this voltage for greater than Fast Over Voltage Time.	Over Voltage to 634 V (L-L)	576	FSTOVL
Fast Over Voltage Time	Establishes the time period allowed for any phase voltage to rise above the Fast Over Voltage limit.	0.03 to 1.00 seconds	0.16	OVFSTM

Over/Under Frequency (Protective Function 81 O/U)

The Over Frequency is adjustable from Under Frequency to 65 Hz; in 0.1 Hz increments (Initial factory setting = 60.5 Hz). The time period is adjustable from 0.01 to 10.00 seconds in 0.01 second increments (Initial factory setting = 0.16 seconds)

The UL1741 requirement for Over Frequency function is:

- The device should cease to energize the output within 0.16 seconds when the grid frequency is higher than 60.5 Hz.

The Under Frequency is adjustable from 45 Hz to Over Frequency, in 0.1 Hz increments. (Initial factory setting = 59.3 Hz). The time period is adjustable from 0.01 to 10.00 seconds in 0.01 second increments. (Initial factory setting = 0.16 seconds)

The UL1741 requirements for Under Frequency function for devices greater than 30kW rating are:

- The device should cease to energize the output within (adjustable 0.16 to 300 seconds) when the grid frequency is lower than (59.8 – 57.0 Hz adjustable set point).
- The device should cease to energize the output within 0.16 seconds when the grid frequency is lower than 57.0 Hz.

As shipped, each C200 microturbine is tested to verify that it meets the UL1741 requirement to initiate a Grid Fault Shutdown, if the line frequency is greater than 60.5 Hz or is less than 59.3 Hz for a duration of 160 ms.

The Over Frequency trip limit may be adjusted downwards as indicated in Table 9-3 and still comply with UL1741.

The Under Frequency trip limit may be adjusted upwards as indicated in Table 9-3 and still comply with UL1741.

The duration to trip may also be adjusted downwards as indicated in Table 9-3 and still comply with UL1741.

Rate of Change of Frequency (Anti-Islanding Protective Function)

The C200 microturbine contains integrated active anti-islanding protective functions. These include an excessive Rate of Change of Frequency protective function, which will cause a Grid Fault Shutdown. The anti-islanding protection is tested and verified as part of the UL1741 listing.

Over Current and Fault Current

In the Grid Connect mode, the total fault current capacity at the installation site is the sum of the fault current from the electric utility grid and that produced by all the on-site generators, including microturbines. The rating of fault current interrupting devices at the site should be checked to ensure that they are capable of interrupting the total fault current available.

The electric utility grid operator will usually wish to be informed of the microturbine fault current contribution in order to assess the impact of the additional fault current on the electric utility grid and customers connected to it. At most installation sites the addition of a Capstone microturbine may not result in a significant increase in the total fault current. However, the potential impact of the increase in fault current should be assessed.

When operating in Grid Connect mode, the C200 microturbine operation is controlled to deliver current corresponding to the power delivery set point (but less than the maximum steady state current of 310 A).

The C200 microturbine does not include passive over current protection, but does provide extremely fast active current control. The microturbine output acts as a current source, using the grid voltage as a reference for both magnitude and phase angle. Active current control ensures that the steady-state current will not exceed 310A per phase, regardless of the utility voltage.

Under transient or fault conditions, active current control and sub-cycle current interruption capability ensure that the RMS current in any half cycle does not exceed 500A RMS. For some severe transients, the inverter may shut down within 1 or 2 cycles due to excessive or unstable current. Even under these conditions, the RMS current in any half cycle will not exceed 500A.

For less severe transients, the active current control will maintain the current at a value not more than 310A RMS. The microturbine will continue to operate in this mode until some other protective function stops power flow. For example, the Fast Under Voltage protective function can be set to detect a reduced utility voltage and initiate a Grid-Fault Shutdown within 160ms.

It is essential for safe operation and service that a circuit protective disconnect device (circuit breaker or fused disconnect) be installed between each C200 microturbine and the utility grid or protected loads. This protective device must be rated for the total fault current, and is intended to protect the microturbine and associated power cables from fault current flowing back from the utility grid and/or other connected microturbines. Local electric codes will almost always require such a disconnect. The added functionality of this protective device is not considered here.

Reverse Power Flow (Protective Function 32)

If the C200 microturbine output is greater than the local load demand, the excess power generated by the microturbine will flow back to the grid. Return flow to the grid may be undesirable for two reasons: 1) The connected electric utility may not allow power to be exported to its grid, and therefore may require that generating equipment cease operation if this condition exists, or 2) The electric utility

may not offer "net metering", and therefore reverse power flow represents an economic loss to the microturbine user.

The C200 microturbine can be configured to provide reverse power flow protection in two different ways. Either method requires an external device be installed at the appropriate point in the distribution circuit to measure power flow. Utilities are normally most concerned about power flow back into their utility grid, and measure this flow at a Point of Common Coupling (or PCC) with onsite generating equipment. The two basic methods are:

- Power meter with pulse outputs to the microturbine
- Reverse power relay with trip signal to the microturbine

Power Meter with Pulse Outputs

The C200 microturbine can be programmed to initiate a Normal Shutdown by installing a power meter with pulse outputs at a remote location between the utility point of common coupling and the point where the microturbine is connected. Detailed requirements for this external equipment are described in Chapter 10: Communications – External Power Meter Inputs.

The reverse power protective function in the C200 may be enabled at installation, and can be configured to initiate a Normal Shutdown when reverse power flow is measured for a duration of 0 to 120 seconds. Note that an overall response time of zero (0) seconds cannot be realistically achieved. The minimum duration depends on the kWh-per-pulse calibration factor of the power meter and the magnitude of the reverse power flow. In practice, if the duration is set as 0 second, the shutdown will be initiated when the first reverse power flow pulse is received. Normal Shutdown allows cooldown of the microturbine to occur as opposed to a Grid Fault warmdown (shutdown) caused by the microturbine's integrated voltage, frequency, and anti-islanding protection. During this cooldown, fuel is shut off but some power will still be output since the main contactor will remain closed and the heat energy stored in the recuperator must be dissipated.

Reverse Power Relay with Trip Signal

Alternatively, a reverse power flow relay may be interfaced with the external fault inputs in the C200's User Connections Bay to initiate a Grid Fault Shutdown when reverse power flow is detected. Details on making a fault input connection are provided in Chapter 10: Communications – Fault Inputs. Typically the fault input would be configured to cause a fault severity level 4 shutdown (warmdown). This scheme will provide the quickest response to a reverse power situation, and will cause an operator to manually clear this severity level 4 fault before the microturbine can be restarted.

NOTE	Some states have rigid requirements regarding proper reverse power flow to the utility during grid disturbances. In this case, the best approach is to use a utility-approved reverse power flow relay to provide a trip signal to the microturbine. The relay trip signal output should interface with one of the microturbine digital fault inputs and be software configured to fault severity level 4 (warmdown). When properly setup, the main output contactor on the C200 microturbine will open to stop exporting power as soon as a trip signal from the reverse power protective relay is detected.

Shutdown

When one or more of the protective relay functions initiates a Grid Fault Shutdown, the microturbine enters the warmdown state and the following events occur:

- The main output contactor is opened within 100 ms; output power flow ceases
- Fuel flow to the turbogenerator stops

During a warm shutdown, control power is supplied from the microturbine generator as it slows down. The warmdown lasts 1-2 minutes before the rotor is stopped. The control software provides for an optional automatic Restart when grid voltage and frequency are within permitted limits for a programmable period of time (adjustable from 5 to 60 minutes).

When a Normal Shutdown is initiated by the Reverse Power Flow function, the microturbine enters the cooldown state and the following sequential events occur:

- Fuel flow to the turbogenerator stops
- A cooldown of the engine takes place lasting up to 10 minutes. During cooldown, the grid power is used to motor the engine.
- The main output contactor is opened upon completion of cooldown.

CHAPTER 10: COMMUNICATIONS

Introduction

This section presents interconnection information for communications between the Capstone C200 microturbine and associated peripheral equipment. All these communications connections are made through the User Connection Bay (UCB), and include the following:

- External Control Inputs
- Operating Mode
- Start/Stop Inputs
- Battery Wake-Up
- Emergency Stop Inputs
- Fault Inputs
- Analog Inputs
- External Power Meter Inputs
- Relay Outputs
- DC Power Outputs
- MultiPac Connections
- RS-232 Serial Communications
- Direct to PC with CRMS software
- To Wireless Modems
- Using Serial to Ethernet Converter
- RS 232 Commands

User Connection Bay

Figure 10-1 shows the location of the User Connection Bay and its associated compartments. Figure 10-2 shows the connector designations on the Model C200 UCB Circuit Board. Connections for External Control, Analog and Power Meter Inputs, Output Relays, MultiPac, and Serial Communications (RS-232) are identified. Descriptions of each of these connections are given below.

WARNING	The User should NOT open the Power Connection Bay within the User Connection Bay (UCB). Potentially lethal voltages exist inside the Power Connection Bay.

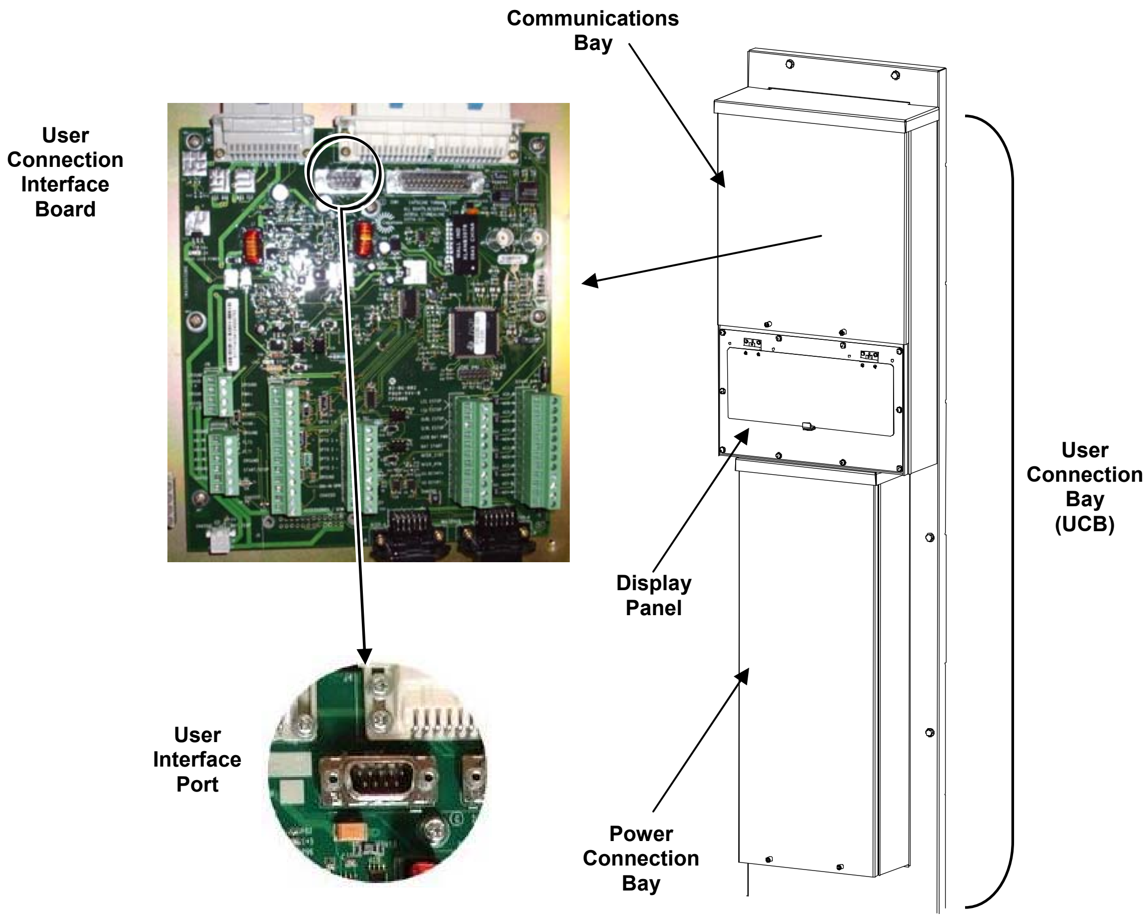


Figure 10-1. User Connection Bay (UCB)

NOTE	All signal level input and output connections should be made using shielded twisted pair and run in separate conduit from power wiring to avoid interference.

NOTE	Maximum wire size for customer terminal connections is 18 AWG. Minimum recommended wire is 20 AWG.

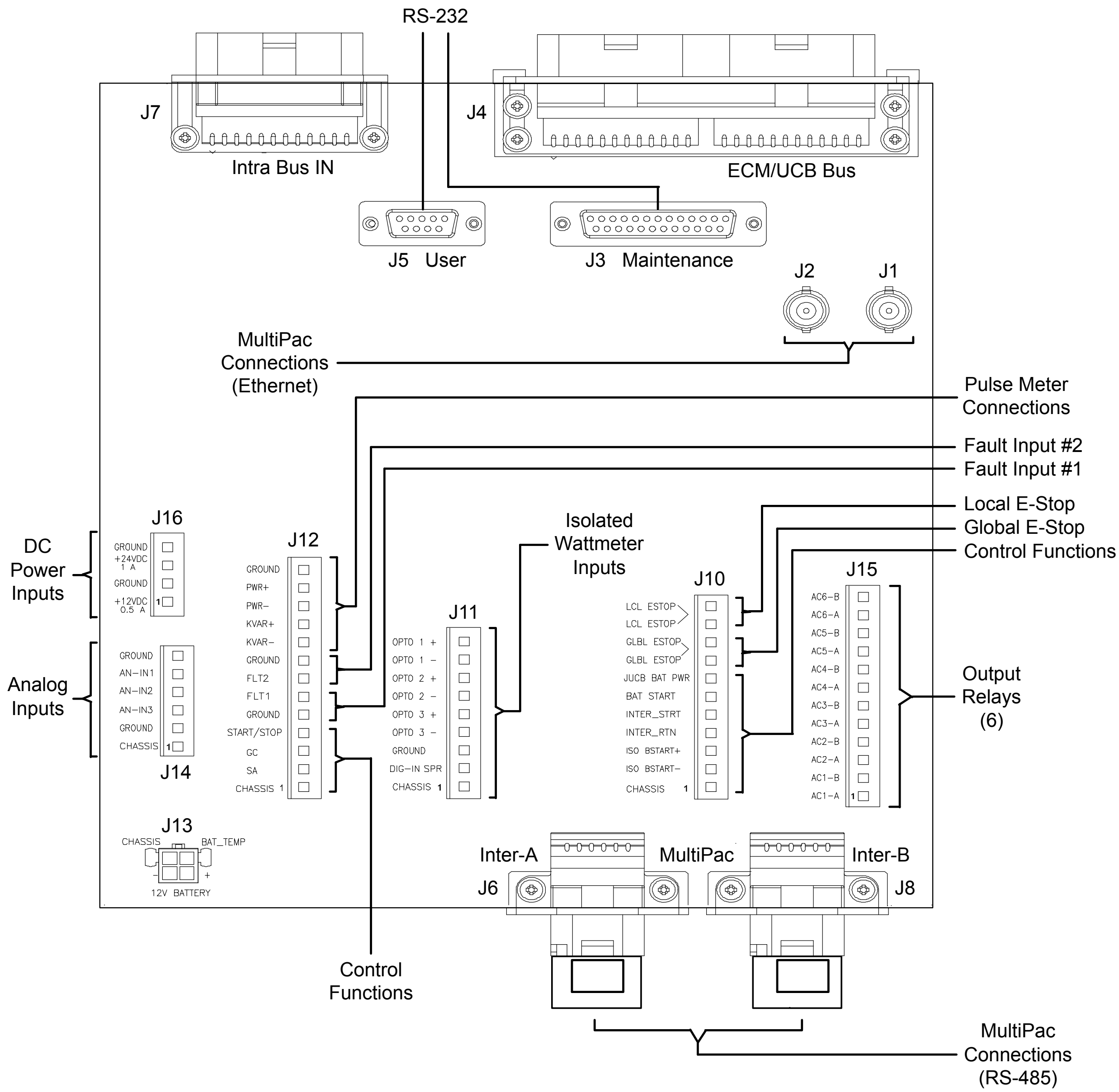


Figure 10-2. Model C200 UCB Connectors

External Control Inputs

Terminal blocks J10 and J12 have specific pins dedicated to external control functions. These include some required connections (such as Grid Connect and Stand Alone enable), as well as several optional control functions. A description of these control inputs is provided below, along with tables showing detailed connection information.

Operating Mode

As described in the Operating Modes section, the C200 microturbine requires both hardware and software inputs to tell it which operating mode to be in. If the system is to be operated only in Grid Connect or Stand Alone modes, a hardwired jumper should be connected as shown in Table 10-1. If the system is to be used in Dual Mode operation, these connections should be controlled externally (such as by using the Capstone Dual Mode System Controller accessory). Configure jumpers or use external contacts for the required operating mode:

Table 10-1. Operating Mode Connection Details

Operating Mode	Terminal J12 Hardware Connections	Power Connect Software Setting
Grid Connect Only	Jumper pins 3 & 5	Grid Connect
Stand Alone Only	Jumper pins 2 & 5	Stand Alone
Dual Mode	Use External contact closures instead of permanent jumpers For GC – pin 3 to 5 For SA – pin 2 to 5	Dual Mode

Start/Stop Inputs

The C200 microturbine can be started and stopped in several ways. The proper connections must be provided on terminal J12 for the desired start/stop control function, and the User/Remote options selected from the External Input Dispatch function using CRMS software.

- User - System is controlled locally through the Display Panel or by using CRMS (no hardwired start input connection required)
- Remote – Start/Stop input connection wired to the UCB.
- Remote SA/User GC – Uses Remote Start priority for Stand Alone operation, and User Start priority for Grid Connect operation (for example, when connected to Dual Mode System Controller)
- Remote GC/User SA – Sets User Start priority for Stand Alone operation, and Remote start priority for Grid Connect operation.
- Configure hardware connections for the required Start Input mode as follows:

Table 10-2. Start/Stop Input Connection Details

Start/Stop Input Mode	Terminal J12 Hardware Connections
User	No connectins
Remote or Combinations of User & Remote	Pin 4 to 5

Refer to Table 10-6 for additional terminal connection information. Note that closing an external contact will initiate a start, and opening this same contact will stop the microturbine.

Battery Wake-Up

Dual Mode C200 microturbines will automatically go into sleep mode if they are not connected to a live utility grid for a preset time. This is to protect their batteries from being discharged, which would result in preventing the microturbine from starting when asked to do so. Means are provided for on the microturbine display to wake a system that is in sleep mode so that a normal start sequence can begin. This action is sometimes referred to as "Battery Start". Refer to the C200 User Manual (400008) for operating the display.

For remote starting a Dual Mode system that is in sleep mode, a momentary contact closure across the battery start contacts on terminal J10 pins 2 and 3 must be provided to wake the system prior to issuing a system start command. Note that this momentary connection may only be closed for .1 to 2.0 seconds to prevent discharge of the UCB battery. Refer to Table 10-4 below for additional terminal information.

Emergency Stop Inputs

Two Emergency Stop (E-Stop) inputs are available in the UCB Communications Bay (see Figure 10-2). The E-Stop inputs are identified as Local and Global E-Stops. These inputs are simple contact closures intended for dry contact circuits, where "closed" means normal operation. Opening a circuit across these inputs initiates an E-Stop.

- Local E-Stop is used on a single microturbine system. When activated, it will stop this microturbine only.
- Global E-Stop is used on MultiPac Configurations. It is connected to one microturbine in the MultiPac. When activated, it will stop all microturbine systems in the MultiPac.

NOTE	If no external E-Stop device is installed, the E-Stop terminals in the UCB must be jumpered.

CAUTION	Emergency stops increase stress on system components. Repeated use of the Emergency Stop feature will result in damage to the microturbine. For most applications, use this only in emergency situations. It is recommended to use other options, such as the fault inputs for emergency stops, for noncritical stops.

Refer to Table 10-3 for E-Stop connection details.

Table 10-3. E-Stop Connection Details

E-Stop	UCB Communications Bay
	Terminal Block (Pin Numbers)
Global	J10 (Pins 8 and 9)
Local	J10 (Pins 10 and 11)

Fault Inputs

Two fault inputs are available in the User Connections Bay. The inputs are accessed through terminal block J12 in the UCB. Fault inputs are simple contact closures intended for dry contact circuits. Refer to Figure 10-6 for fault input connection details.

The following settings are available for Fault Inputs:

- Enable/Disable (On/Off) - If On, control detects a fault input into the system from an external fault source.
- Fault Level - defines the system severity level of this fault source. Refer to Table 10-4.
- Time (sec) - adjusts the debounce time for fault input detection from an external device, i.e. how much time the fault is detected for before the fault is latched in the system.
- Polarity– selects Normally Closed (Active Open) or Normally Open (Active Closed) logic polarity.
- Refer to the CRMS Technical Reference User's Edition (410013) for how to set these inputs.

The available severity level settings for the fault inputs are 2, 3 or 4. Table 10-4 summarizes what each of these severity levels means in terms of shutdown and restart functions.

Table 10-4. Fault Severity Settings and Functionality

Fault Severity Level	Microturbine Stop	Auto Restart	Comments
2	No	N/A	Fault is logged, but no action taken
3	Yes	Yes - 5 Restart Attempts	Restart attempts will occur even if fault input signal remains active
4	Yes	No	Fault input signal must return to normal and operator must manually clear fault before restarting

Terminal Blocks J10 and J12 Connection Details

Table 10-5 and Table 10-6 below provide additional details about the external control connections.

Table 10-5. Connector J10 – Miscellaneous I/O Connections

Pin	Signal	Parameter
J10 (1)	Chassis Ground	To be used for cable shield connections
J10 (2)	Wake-up signal if asleep (Input) Return	Isolated return for signal of J10 (3)
J10 (3)	Wake-up signal if asleep (Input)	Momentary (0.1 to 2 seconds) input +4 to +15 V with respect to J10 (2). Opto-isolated (±150 VDC maximum to earth)
J10 (4)	Inter Start (Input/Output) Return	Return for signal of J10 (5) (Note 1)
J10 (5)	Inter Start (Input/Output)	(Output) = MultiPac start signal, +24 VDC, 30 milliamps/0.7 Amps maximum, momentary (0.1 to 2 seconds), 27 C200 units maximum connections. (Input) = 755 ohms load (Note 1)
J10 (6)	Internal Battery Wake Signal (Input)	+5 V to Ground, Z_{in} = 130 k ohms RESERVED – Do not connect external circuits. Use J10 (2) and J10 (3) for battery wake-up (Note 1)
J10 (7)	JUCB Battery Power (Output)	+12 V JUCB Battery Power, 0.6 Amps re-settable fused (Note 2)
J10 (8)	Global E-Stop (Input)	Return for J10 (9) (Note 1)
J10 (9)	Global E-Stop (Input)	MultiPac dry circuit contact closure. Closed for normal operation, open for E-Stop. (+) 24 VDC @ N*42 milliamps (Note 1)
J10 (10)	Local E-Stop (Input)	Return for J10 (11) (Note 1)
J10 (11)	Local E-Stop (Input)	Dry circuit contact closure. Closed for normal operation, open for E-Stop. (+) 24 VDC @ 42 milliamps (Note 1)

Notes:

(1) Connections made to these terminals MUST be Dry Circuit rated and isolated from ground/chassis. They may not be connected in parallel with other microturbine input terminals.

(2) Connections made to this terminal MUST be isolated from ground/chassis. It may not be connected in parallel with other microturbine input and/or power supply terminals.

Table 10-6. Connector J12 – Contact Closure Inputs

Pin	Signal	Parameter
J12 (1)	Chassis Ground	To be used for shield connections
J12 (2)	SA (Stand Alone mode)	Dry circuit closure to AGND from (+) 5 Volt pull up, 4.7 k ohms (Note 1)
J12 (3)	GC (Grid Connect mode)	Dry circuit closure to AGND from (+) 5 Volt pull up, 4.7 k ohms
J12 (4)	Start/Stop	Dry circuit closure to AGND from (+) 5 Volt pull up, 4.7 k ohms (Note 1)
J12 (5)	AGND	Return circuit for connector J12 contact closures (Note 1)
J12 (6)	FLT1 (User Fault Input)	Dry circuit closure to AGND from (+) 5 Volt pull up, 4.7 k ohms (Note 1)
J12 (7)	FLT2 (User Fault Input)	Dry circuit closure to AGND from (+) 5 Volt pull up, 4.7 k ohms (Note 1)
J12 (8)	AGND	Return circuit for connector J12 contact closures (Note 1)
J12 (9)	KVAR (-) (Wattmeter)	Dry circuit closure to AGND from (+) 5 Volt pull up, 4.7 k ohms (Note 1)
J12 (10)	KVAR (+) (Wattmeter)	Dry circuit closure to AGND from (+) 5 Volt pull up, 4.7 k ohms (Note 1)
J12 (11)	PWR (-) (Wattmeter)	Dry circuit closure to AGND from (+) 5 Volt pull up, 4.7 k ohms (Note 1)
J12 (12)	PWR (+) (Wattmeter)	Dry circuit closure to AGND from (+) 5 Volt pull up, 4.7 k ohms (Note 1)
J12 (13)	AGND	Return circuit for connector J12 contact closures (Note 1)

Note:

(1) Connections made to these terminals MUST be Dry Circuit rated and isolated from ground/chassis. They may not be connected in parallel with other microturbine input terminals.

Analog Inputs

The C200 microturbine provides three user-configurable analog inputs at the UCB location. The function for each input can be selected independently from the following options:

- Not assigned
- Electrical Power demand

These three analog inputs can be individually configured for 0-5 VDC or 4-20mA signals. The electrical signal type and the function can be set using CRMS. Refer to CRMS Technical Reference User Edition (410013) for configuring these inputs. Figure 10-3 and Figure 10-4 show example connections to the analog inputs for 4-20 mA and 0-5 VDC signal types. Note that for analog signals, the UCB provides the voltage source.

Table 10-7 provides details of the analog inputs on terminal block J14.

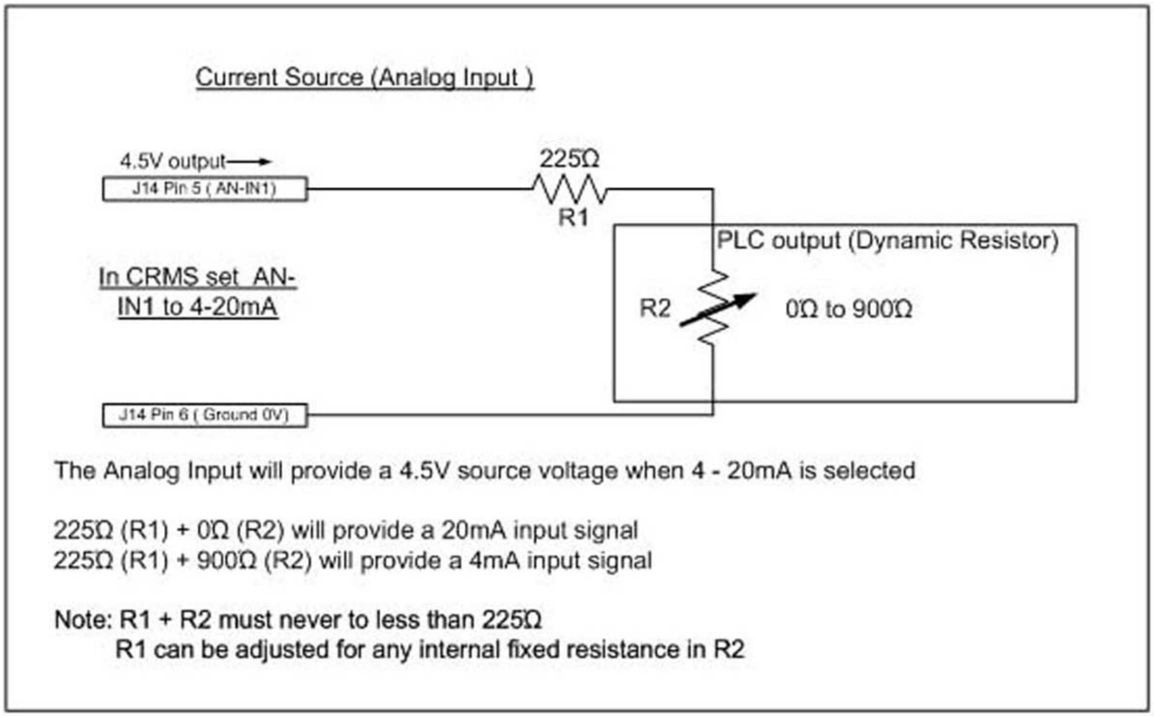


Figure 10-3. 4-20mA Current Source Analog Input Example

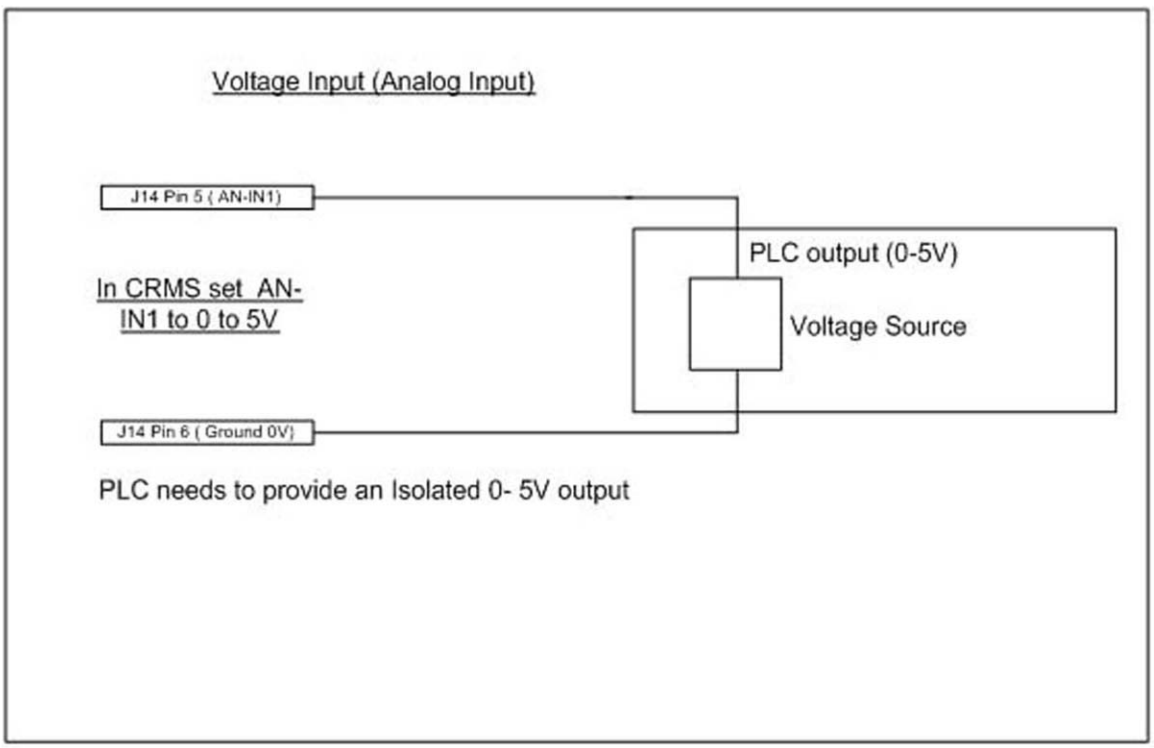


Figure 10-4. 0-5V Voltage Source Analog Input Example

Table 10-7. Connector J14 – Analog Inputs

Pin	Signal	Parameter
J14 (1)	Chassis Ground	To be used for shield connections
J14 (2)	AGND	Return for analog signals. Impedance =10 ohms
J14 (3)	ANIN3	0 to (+) 5 VDC, high impedance
J14 (4)	ANIN2	0 to (+) 5 VDC, high impedance
J14 (5)	ANIN1	0 to (+) 5 VDC, high impedance
J14 (6)	AGND	Return for Analog Signals. Impedance = 10 ohms

External Power Meter Inputs

The Load Following and Reverse Power Flow functions require the installation of a 3-phase power meter at a remote location from the microturbine. Microturbine hardware and software is designed to accept signals from a pulse-output power meter. See Figure 10-5 and Figure 10-6 for power meter connections.

Pulse-output power meters provide a contact closure pulse indicating when a specific amount of energy has passed through the meter. The quantization of energy per pulse is either fixed or programmable depending upon the meter.

There are two sets of contact closure inputs. One set provides contact pulses for forward energy flow, and the other set provides energy for reverse energy flow:

- Power flow in the forward direction (toward the loads) is measured as +PWR.
- Power flow in the reverse direction is measured as –PWR.

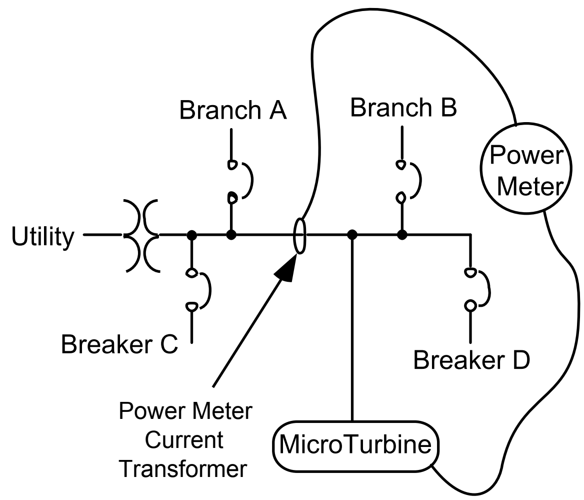


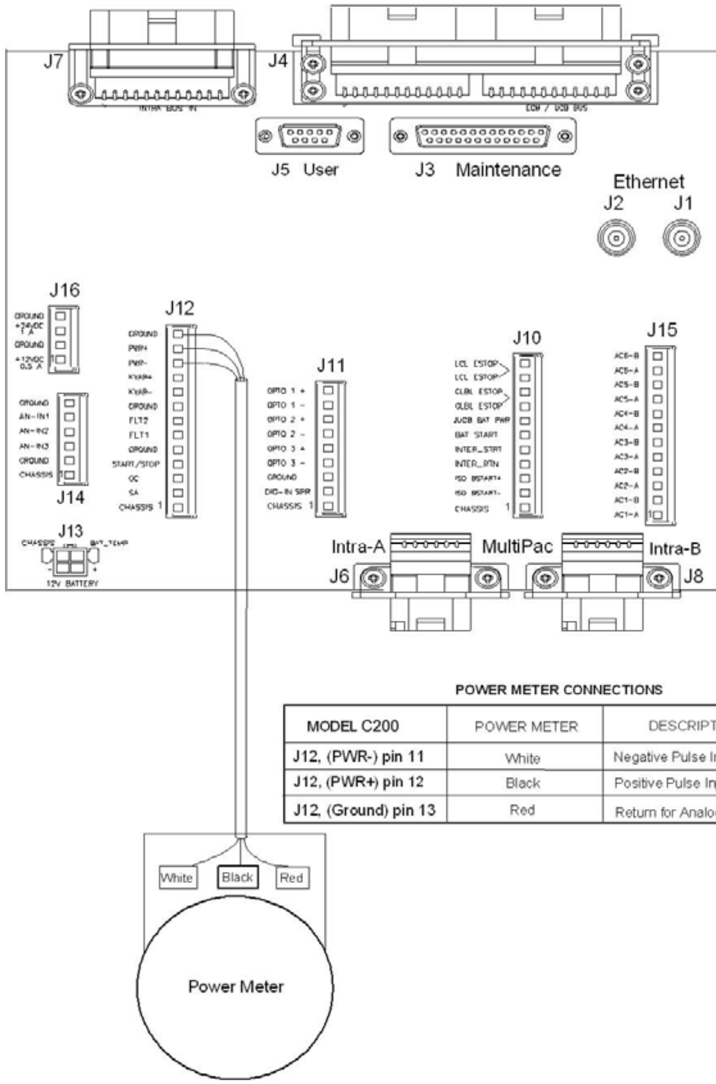
Figure 10-5. Typical Power Meter Interconnection

The external power meter should be placed in a location to produce the demand signal. Loads on the load side of the power meter current transformer location will produce demand signals, load on the utility side will not. The demand on the microturbine will be calculated as the difference between the Utility Power setting entered during this setup and the actual load measured by the power meter.

For example, in Figure 10-5, loads on Branches B and D only will determine the microturbine power output demand. Branch A or C loads have no effect. The microturbine may be connected at breaker location, B or D (or an entirely different circuit). Power output demand will still be determined by the flow through the power meter current transformers.

A power meter providing dry contacts for the pulse outputs would be connected to the UCB on terminal J12, as shown in Table 10-6 above and Figure 10-6 below.

A power meter providing voltage (+5 to 15 VDC only) for the pulse outputs would be connected to the UCB using the opto-isolated connections on terminal J11, as shown in Table 10-8 below.



POWER METER CONNECTIONS

MODEL C200	POWER METER	DESCRIPTION
J12, (PWR-) pin 11	White	Negative Pulse Input (PWR-)
J12, (PWR+) pin 12	Black	Positive Pulse Input (PWR+)
J12, (Ground) pin 13	Red	Return for Analog Ground

Figure 10-6. Power Meter Connections

Table 10-8. Connector J11 – Opto-Isolated Inputs from Wattmeter

Pin	Signal	Parameter
J11 (1)	Chassis Ground	To be used for shield connections
J11 (2)	DIGINSP	0-5 Volt Analog Signal – NOT USED
J11 (3)	AGND	Analog Ground for J11 (2). Impedance =10 ohms
J11 (4)	OPTO 3 (-)	Isolated return for J11 (5). Isolated. (150 VDC maximum to earth)
J11 (5)	OPTO 3 (+)	KVAR Pulse Train from Wattmeter (+5 to +15 V, Z_{in}= 1 kohm, Isolated) (150 VDC maximum to earth)
J11 (6)	OPTO 2 (-)	Isolated return for J11 (7). Isolated. (150 VDC maximum to earth)
J11 (7)	OPTO 2 (+)	Negative Power Pulse Train from Wattmeter (+5 to +15 V, Z_{in}= 1 kohm, Isolated. (150 VDC maximum to earth)
J11 (8)	OPTO 3 (-)	Isolated return for J11 (9). Isolated. (150 VDC maximum to earth)
J11 (9)	OPTO 3 (+)	Positive Power Pulse Train from Wattmeter (+5 to +15 V, Z_{in}= 1 kohm, Isolated. (150 VDC maximum to earth)

Programming the Meter Scaling Constant

Each power meter has an internal calibration factor supplied with the electronics. This internal calibration factor may have to be modified by multiplicative factors associated with the current and potential transformers employed between the power meter and the power wiring. Thus, the overall calibration factor seen by the microturbine is as follows:

$$K_e = K_h / (P/R) * CTR * PTR / DIV$$

where:

Ke = Scaling constant for pulses entering the microturbine terminals, W-h/pulse

Kh = A typical Kh is 1.8 W-Hr per revolution; power meter internal calibration factor, W-h/revolution (usually found on meter face).

CTR = Current transformer ratio (current at power meter /current in lines);
Example: A 2000A to 5A current transformer would have a CTR of 2000/5 = 400

PTR = Potential transformer ratio (voltage at power meter / voltage at bus).
Example: A 480 V to 120 V potential transformer would have a PTR of 480/120 = 4

DIV = Any other division ratio applicable to the power meter.

P/R = Pulse per revolution (usually found on meter face)

Ke is the scaling constant that should be entered into the display controller. The power meter internal calibration factor, current transformer ratio and voltage transmitter ratio must be such that the scaling constant falls in the range 0 – 500.000 W-h/pulse.

Relay Outputs

A total of six solid state output relays are available to signal selected operating conditions to external equipment. The functions to operate each relay must be configured using CRMS software. Refer to the CRMS Technical Reference User's Edition (410013) for how to configure these relays. Table 10-9 describes the available functions.

Table 10-10 provides details for the output connections on terminal block J15.

Table 10-9. Available Output Relay Functions

Function	Description
Standby	Function is true when the system is in the Standby state.
Run	Function is true when the engine is running or power electronics are enabled.
Contr Closed	Function is true when the Output Contactor is closed.
Fault	When a fault is active, this setting is true when the system active faults create a severity level greater than a warning.
Stand Alone	If the microturbine is in the Stand Alone mode, this function is true.
SA Load	If the microturbine is in the SA mode and in the Load State, this function is true.
Disable	When the system is in the Disable state, this function is true.
Fuel On	This function is true when the electrical fuel shut-off is enabled.
Fuel Purge	Contact will be true for 10 seconds after the main fuel shutoff is closed (for units equipped with liquid fuel only).
Load State	This function is true if the system is in the Load State (GC or SA).
External Load	The relay indicates when the external load may be engaged, i.e., IGBTs are enabled. For example, the relay can be used to run/stop the fuel gas booster in low-pressure systems.
PRT RLY FLT	This function is true when the system active faults have an isolation message of "PRT RLY Fault" (Protective Relay Fault).
ANT-ISL FLT	This function is true when the system active faults have an isolation message of "ANTI-ISL Fault" (Anti-Islanding Fault).
Not Assigned	No software function assigned to this hardware output relay (Initial factory setting).
CHP Active (If installed)	Signal is active when the system detects microturbine exhaust gas flow.

Table 10-10. Connector J15 – Solid-State Relay Outputs

Refer to Note 1 below for solid-state relay contact general information.

Pin	Signal	Parameter
J15 (1)	AC1-A	AC1 line, 25 VAC maximum voltage, 100 milliamps maximum current
J15 (2)	AC1-B	AC1 load, 25 VAC maximum voltage, 100 milliamps maximum current
J15 (3)	AC2-A	AC2 line, 25 VAC maximum voltage, 100 milliamps maximum current
J15 (4)	AC2-B	AC2 load, 25 VAC maximum voltage, 100 milliamps maximum current
J15 (5)	AC3-A	AC3 line, 25 VAC maximum voltage, 100 milliamps maximum current
J15 (6)	AC3-B	AC3 load, 25 VAC maximum voltage, 100 milliamps maximum current
J15 (7)	AC4-A	AC4 line, 25 VAC maximum voltage, 100 milliamps maximum current
J15 (8)	AC4-B	AC4 load, 25 VAC maximum voltage, 100 milliamps maximum current
J15 (9)	AC5-A	AC5 line, 25 VAC maximum voltage, 100 milliamps maximum current
J15 (10)	AC5-B	AC5 load, 25 VAC maximum voltage, 100 milliamps maximum current
J15 (11)	AC6-A	AC6 line, 25 VAC maximum voltage, 100 milliamps maximum current
J15 (12)	AC6-B	AC6 load, 25 VAC maximum voltage, 100 milliamps maximum current

Note 1: These contacts must only be connected in Class 2 circuit for limited voltage and limited current power source at maximum voltage of 25 VAC. If switching at higher voltages and currents is required, please contact Capstone Applications for recommendations.

DC Power Outputs

The UCB includes 12 VDC and 24 VDC outputs for use by a modem or other communications accessory. The 12 VDC power is always available and is fed from the small internal battery in the system controller. This power allows the user to install a modem and remotely call up a unit even if it is off. The 24 VDC power is fed from the system's internal low power DC bus and is only available when the unit is awake/on.

Table 10-11 provides details for terminal J16, which provides these DC outputs.

Table 10-11. Connector J16 – Modem and User Power Outputs

Pin	Signal	Parameter
J16 (1)	Modem Power	12 VDC, 0.5 Amps maximum (re-settable fuse protected) (Note 1)
J16 (2)	PWRGND	Modem Power Return (Note 1)
J16 (3)	User Power	24 VDC, 1 Amp maximum (re-settable fuse protected) (Note 1)
J16 (4)	PWRGND	User Power Return (Note 1)

Note:

(1) Connections made to these terminals MUST be isolated from ground/chassis. They may not be connected in parallel with other microturbine input and/or power supply terminals.

MultiPac Connections

Two types of signal connections are required on the UCB for MultiPac communication:

1) Ethernet (Terminals J1 and J2)

2) RS-485 Inter-Cable Harness (Terminals J6 and J8).

The interconnection diagram in Figure 10-7 shows these two types of signal interconnections, along with the required signal terminations.

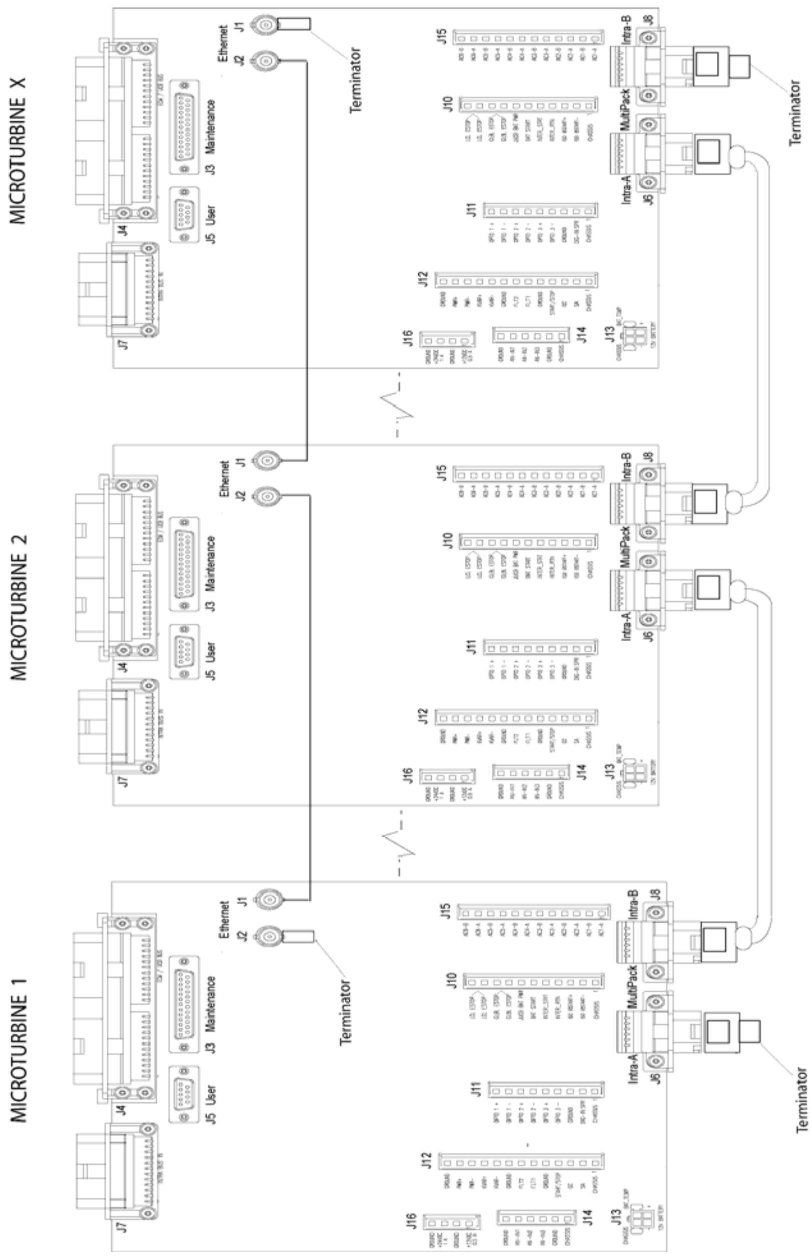


Figure 10-7. MultiPac Signal Interconnections

Ethernet

Ethernet signals are used for command and control. Commands (i.e. start/stop, power demand) are input to the Master. The Master then sends resulting commands to each microturbine in the MultiPac. The Master routinely queries microturbines for operational and fault data. Users can request data from any turbine through the Master.

NOTE	Maximum total RG58A/U coaxial cable length is 185 meters.

RS-485 Inter-Cable

An RS-485 Inter-cable harness transfers hardware signals between microturbines. The RS-485 harness is not needed if operating in Grid Connect mode with no Global E-stop configured.

NOTE	Maximum total RS-485 cable length is 1000 meters.

RS-485 Inter-cable harness is used to communicate:

- Inverter synchronization (Stand Alone only); one turbine serves as an Inverter Master, passing voltage and frequency signals to all other turbines for synchronization. Note that the Inverter Master does not have to be the MultiPac Master.
- Global E-stop – Wired to one turbine (typically the MultiPac Master), which shuts down all other turbines when opened.
- Battery Wake-up – Wired to one turbine (typically the MultiPac Master), which wakes up all other turbines for Stand Alone operation

Signal Terminations

Signal terminators MUST be present on the initial and final connection for both Ethernet coax and RS-485 inter-cable harness connections. If terminations are not present, electrical ringing may be present, and the signal may be severely degraded or interrupted.

Cable Connection Details

Capstone offers pre-terminated MultiPac cable sets to simplify field wiring, which include an Ethernet coax cable, RS-485 Inter-cable harness, and end terminators for both the coax and RS-485 cables. Table 10-12 provides reference information about the RS-485 Inter-cable connections to terminals J6 and J8.

Table 10-12. Connectors J6 & J8 – Inter-Controller RS-485 Port

Pin	Signal	Parameter
J6 or J8 (A)	Serial Communication	RS-485, Bus A Protocol (Note 1)
J6 or J8 (B)	(Not Applicable)	Chassis Ground
J6 or J8 (C)	Inter-Controller Start	+24 VDC @ 15 milliamps per microturbine (Refer to Table 10-13)
J6 or J8 (D)	(Not Applicable)	Chassis Ground
J6 or J8 (E)	Global E-Stop	Normal Operation: N*85 milliamps. E-Stop: (+) 24 VDC (Refer to Table 10-13)
J6 or J8 (F)	(Not Applicable)	Chassis Ground
J6 or J8 (G)	(Not Applicable)	Spare
J6 or J8 (H)	E-Stop Return	Normal Operation: N*85 milliamps. E-Stop: 0 VDC
J6 or J8 (J)	(Not Applicable)	Reserved
J6 or J8 (K)	Inter-Controller Start Return	30 milliamps per microturbine @ 0 VDC
J6 or J8 (L)	(Not Applicable)	Reserved
J6 or J8 (M)	Serial Communication	RS-485, Bus B Protocol

Notes:

(1) Whenever J6 is at the extremities of the RS-485 multi-drop network; Capstone-provided terminators must be installed. The maximum number of nodes is 32, and the maximum RS-485 cable length is 1000 meters. Each microturbine has 1.93 meters of internal cable length, which must be included in the total length considerations. Repeaters may be added whenever the maximum cable lengths or the maximum number of nodes are exceeded.

The RS-485 inter-cable harness actually includes three twisted pairs with a common shield. One twisted pair is used for RS-485 communications. The second twisted pair is used for inter-controller start (battery wake-up). The third twisted pair is used to communicate a Global E-Stop.

Table 10-13 provides application guidance on limitations of each of the control functions. Please contact Capstone if your application is outside of these limits.

Table 10-13. Twisted Wire Pair Limits

Wire Pair	Limits
RS-485 Serial Communications	1000m total cable length (refer to Note 1 above)
Inter-Controller Start (Battery Wake-Up)	Maximum 20 microturbines
Global E-Stop	Maximum 20 microturbines and 100 meter total cable length

RS-232 Serial Communications

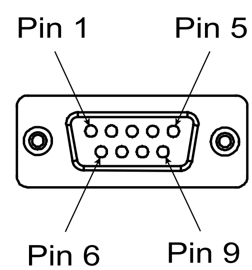
Overview

The C200 microturbine provides two RS-232 ports on the UCB. A PC or PLC device may be connected to the UCB for monitoring, configuring, controlling, or troubleshooting a microturbine system. The microturbine communicates via RS-232 protocols using a null modem cable with hardware handshaking. A DB9 connector (User Port) and a DB25 connector (Maintenance Port) are available. If devices are connected to both ports, the port accessed at the higher security password level has priority for command of the system. If both are at the same password level, the Maintenance Port has priority.

DB9 Connector (User Port)

The User Port is a 9-pin RS-232 connector and is identified as J5 on the UCB. Pin designations are shown in Table 10-14.

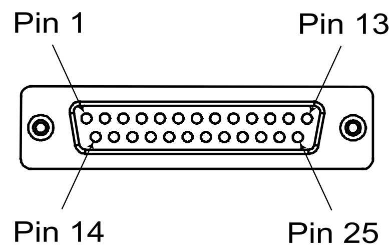
Table 10-14. J5 User Port DB9 Pin Designations

Pin No.	Signal	Description	RS-232 Connector (DB9)
1	DCD	Data Carrier Detect	
2	RXD	Receive Data	
3	TXD	Transmit Data	
4	DTR	Data Terminal Ready	
5	SG	Signal Ground	
6	DSR	Data Set Ready	
7	RTS	Request to Send	
8	CTS	Clear To Send	
9	RI	Ring Indicator	

DB25 Connector (Maintenance Port)

The Maintenance Port is a 25-pin RS-232 connector and is identified as J3 on the UCB. Pin designations are shown in Table 10-15.

Table 10-15. J3 Maintenance Port DB25 Pin Designations

Pin No.	Signal	Description	RS-232 Connector (DB25)
2	TXD	Transmit Data	
3	RXD	Receive Data	
4	RTS	Request to Send	
5	CTS	Clear To Send	
6	DSR	Data Set Ready	
7	SG	Signal Ground	
8	DCD	Data Carrier Detect	
20	DTR	Data Terminal Ready	
22	RI	Ring Indicator	

Null Modem (or Modem Eliminator) Cable

A null modem cable is used for connecting two computers together without a modem. It is a RS-232 cable that interchanges conductors 2 and 3. It is also known as a modem eliminator. Wiring connections for null modem cables with DB9 connector (see Figure 10-8) and DB25 connector (see Figure 10-9) are as follows:

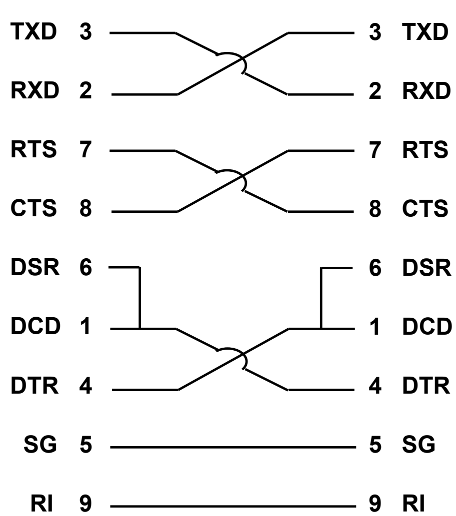


Figure 10-8. DB9 Null Modem Cable

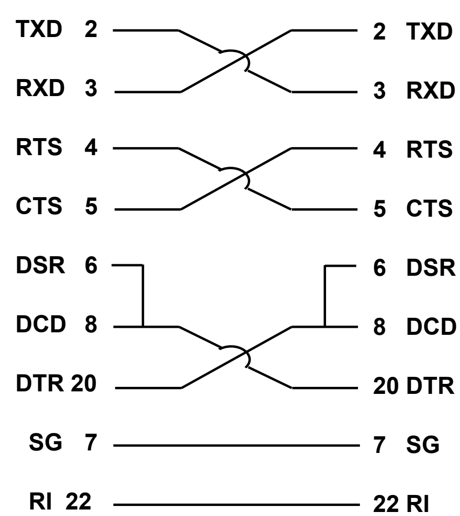


Figure 10-9. DB25 Null Modem Cable

Connections to Third-Party Modems

The following paragraphs present connection details between the microturbine and the third-party modems.

Modem Power

The modem can be powered from the power supply available in the UCB box (refer to Table 10-11, J16). Make sure the current rating of the modem does not exceed that of the power supply.

Communications Cable

The modem can be connected to the User Port or Maintenance Port of the microturbine. Typically, it is connected to the Maintenance Port. A straight-through serial cable is required in most cases for data connection between the modem and the microturbine.

Modem and Microturbine Settings

The microturbine port speed setting must be set to the same speed as the modem.

The initial factory setting hardware configuration for the User and Maintenance Ports is 57,600 bits per second (maximum speed), 8-bit word length, no parity, one stop bit, and hardware handshake for flow control. It is recommended to use the highest speed available on the modem, not exceeding the maximum speed of the microturbine port.

Upon initialization, the microturbine sends an AT&F command to restore the factory settings of the modem. If this affects the desired settings on the modem, the DSR and DCD pins can be jumpered in the serial cable connecting the modem to the microturbine. This will prevent the MT from sending the AT&F command.

Some telemetry modems have different modes for data packet transmission. For the microturbine to communicate properly, the transmitted data packets should never be split. For example, some modems have a mode (for example DOX mode), by which the data packets are kept together during transmission.

Some modems also offer a TCP/IP connection instead of a serial connection. These modems would require the use of Serial to Ethernet Converters, but would allow a single modem to be used to access multiple microturbines at the same site.

Wireless Modems

For remote microturbine installations where no landline telephone service is available, a radio or cellular modem is highly recommended for monitoring and troubleshooting the microturbine system. Several third-party cellular and radio modems have been successfully used with the Capstone microturbines.

Resources for Wireless Modems

A list of recommended modem vendors and model numbers that may be suitable for installation at your location is presented below. Contact your local cellular telephone service companies for a list of cell modems with coverage in your area. For telemetry and radio modems, be aware of local and FCC regulations, as well as permits required for using air radio frequencies. The usage of some radio frequencies may require special licenses.

NOTE	Cellular modem models and brands vary greatly depending on the service offered in your area. Contact your local telephone companies for the service and models available.

Cellular Modems:

Manufacturer:	Airlink
Website:	www.airlink.com
Model:	Airlink Raven II CDPD

Manufacturer:	Motorola
Website:	www.motorola.com
Model:	781GWTY164Y

Radio/Telemetry Modems:

Manufacturer:	Data Radio
Website:	www.dataradio.com
Model:	Integra H

Manufacturer:	Locus Inc.
Website:	www.locusinc.com
Model:	OS2400–485

Serial to Ethernet Converter

The Serial to Ethernet Converter is a stand-alone converter device that provides the ability to use Capstone microturbine RS-232 commands over a TCP/IP 10/100 Base-T network connection. The converter can be used for communication over a LAN or the internet between a microturbine and a PC using CRMS.

There are two versions of the Serial to Ethernet converter available, a single-port and a dual port. The single port version allows only one user to be connected at a time to the microturbine. This version is typically used in conjunction with the Capstone Service Network. Refer to the Capstone Service Network User Manual (400016) for additional details. The two port version is used when two or more users (up to eight) are required to be connected to the microturbine simultaneously. This version is typically used when multiple users are required to monitor one microturbine at the same time. Some examples are when the microturbine will be controlled by a Capstone CID2 Controller or a third party controller, while being monitored by another user with CRMS. Note that in order for a third party controller to be able to communicate with a microturbine through the converter, the controller must be capable of transmitting the Capstone

ASCII Protocol over TCP/IP. Refer to RS-232 Direct Command Line Interface below for more details.

For further information on installing and configuring the Serial to Ethernet converters, refer to the Serial to Ethernet Converter Technical Reference (410049).

RS-232 Direct Command Line Interface

Command Structure

The basic paradigm of the communications interface is query-response from a prompt message, with the external device providing the query to a UCB serial communications port. Each query sent to a UCB serial communications port contains a message. A typical message consists of a command, an optional turbine identification number, and command arguments. Arguments provide additional information to process the command.

```
<msg>      -> <cmd> [,<turb#>] [=<args>]
where,
<cmd>      -> 6 ASCII characters identifying function to execute
<turb#>    -> turbine number
<args>     -> sequence of ASCII text supplied to the <cmd>. See
              details on commands defined below.
```

All white space characters (includes carriage return, line feed, space, and tab characters) are ignored by the UCB.

In a multiple unit environment, all external devices connect to the MultiPac Master. Communications to other units in a multiple unit installation is routed automatically through the Master unit. The Master system is always turbine number 1.

RS-232 Query Protocol

Data transmissions over the RS-232 interfaces are protected with a proprietary communication protocol syntax that encapsulates each message. Error detection is provided in the protocol through ASCII character message synchronization and a verification checksum. Error correction is performed by re-sending the message. Each transmission packet sent is considered a query. Syntax for issuing commands via the RS-232 query protocol is provided below.

```
<query>    -> <SOH> <length> <msg> <crc16> <EOT>
where,
<SOH>      -> ASCII character 01h
<length>   -> number of bytes transmitted
<crc16>    -> 16-bit CRC calculation of all <msg> data. Transmit
              low order byte first.
<EOT>      -> ASCII character 04h
```

CRC-16 Calculation

Calculating a CRC16 is performed using the following method:

1. Initialize the 16-bit CRC value to 0xFFFF
2. Exclusive-OR (XOR) the byte with the 16-bit CRC
3. When low bit of 16-bit CRC is 1, shift the entire word right 1-bit, Exclusive-OR (XOR) with 0xA001, and proceed to step 5
4. Repeat step 3 for all 8 bits of each byte
5. When low bit of 16-bit CRC is 0, shift the entire word right 1-bit
6. Repeat from step 2 for each byte in sequence

The 16-bit CRC is appended to the message low-byte first followed by high-byte. (NOTE: performing a CRC16 calculation on a stream of bytes with its CRC16 value appended will always result with the value 0x0000).

Sample "C" Code:

The following is sample C-code for the CRC error checking.

```
static UWORD crc_add (UCHAR *data, UWORD length, UWORD crc_reg)
{
   int i;

   while (length--) {

      crc_reg ^= *data++;

      for (i = 0; i < 8; ++i)
         if (crc_reg & 1)
            crc_reg = (crc_reg >> 1) ^ 0xa001;
         else
            crc_reg >>= 1;
   }

   return crc_reg;
}
```

Example Command Syntax

The following shows the bytes for writing the command **ALLDAT** to the serial port.

SOH	Length	A	L	L	D	A	T	CRC1	CRC2	EOT
0x01	0x06	0x41	0x4c	0x4c	0x44	0x41	0x54	0x79	0xee	0x04

RS-232 Response Protocol

Responses to query messages will use the same encapsulation protocol described in the section for RS-232 Query Protocol. The response structure is identical to the command structure, but provides complete information for each message (<msg>) including turbine number and a full list of arguments.

Output responses will conform to the following standards based on the data type:

Table 10-16. Standard Data Types

Format	Description	Applicable Data Types
MM/DD/YYYY		Date
HH:MM:SS	HH is the hour based on a 24-hour clock	Time
Decimal Integer		Faults, States
Hexadecimal		Bit Packed Value, Memory Patterns, Idents
Floating point	scientific notation ±0.0000e±00	Acquisition Data
String	All alphabetic characters are capitalized	Strings

All units will be expressed in metric (SI) units (i.e. °C, RPM, V, A, kW, kPa) as the default. The user may adjust the display format to use English units (i.e. °F, psi).

Sign On Message

During power up, the system executes the boot software program to verify the operational programs checksum and provide download capability on either the user or maintenance port. During the boot process, the ports will not accept any messages. The following text is output to both the user port and the maintenance port:

```
“Capstone Turbine Corporation - Microturbine Generator”
“Boot Version X.XX”
```

The following text is transmitted on the maintenance port once the operational program checksum verification and internal self-checks are complete:

```
“Software Version X.XX”
“MNT>”
```

User Password Levels

Password levels available on the user and maintenance ports provide security at two levels:

Table 10-17. Password Levels and Prompts

Password Level	User Port Prompt	Maintenance Port Prompt
Base	USR>	MNT>
Protected	USRPRT>	MNTPRT>

When powered up the user and maintenance ports boot into the “Base” level. No password is required to operate basic data acquisition commands.

To transition to the “Protected” password level, enter the corresponding password. Each system then has a user-defined password that grants “Protected” password level authorization. The initial factory set user password “**USR123P**” is programmed into the system at manufacturing. At the “Protected” level the user has access to system control functions (starting and stopping), protecting operation of the machine via the RS-232 user port through casual access.

User Prompts Display Password Level

On the user port there is a standard default prompt of “USR>” that specifies “Base” level security is active and no password has been issued. Issuing the protected level password and verification transitions the user port to the “Protected” level where a “USRPRT>” prompt is displayed.

The maintenance port has a standard default prompt of “MNT>”. Issuing the protected level password and verification transitions the maintenance port to the "Protected" level where a "MNTPRT>" prompt is displayed.

User Prompts Display Password Level

For a complete list of commands and their descriptions, contact Capstone.

CHAPTER 11: MAINTENANCE

The C200 microturbine System requires little maintenance due to its robust design and use of air bearings. The use of air bearings, coupled with the fact that the microturbine system does not incorporate a mechanical transmission, means that no lubricants or coolants need to be periodically replaced or disposed of.

Scheduled Maintenance

Refer to the Capstone Standard Maintenance Schedule Work Instruction (440000) for details on the recommended service items and times.

Battery Life

Battery life expectancy is dependent on several factors, but is most strongly dependent on operating temperature and the number of times the batteries are used to start the C200 microturbine. Operating temperatures are a function of the ambient temperature as well as the temperature rise due to repeated load cycling.

Battery life can therefore be estimated by multiplying the base life times temperature derating and start derating factors. Provided the battery is maintained by appropriate equalization charges, a base life of 26,282 hours should be used.

Expected life = Base Life x Temperature Derating x Starts Derating

Example:

Ambient temperature = 30 °C

40 kW load transient every 200 seconds

200 Starts per Year

Step 1: Base Operating Hours.

Start with a base number of operating hours for 3 years or 26,280 hours.

Step 2: Find the Operating Temperature of the Battery.

Using Figure 11-1, find the temperature increase over ambient for the given transient load size and the transient interval. The Temperature increase over ambient can be read from the y-axis on this figure. Add this value to the ambient temperature to get the battery temperature during operation; in this example 30 + 5 = 35 °C.

Step 3: Find the Temperature Derating of the Battery.

Using Figure 11-2, find the battery temperature (30 + 5 = 35 °C) on the x-axis and read the derating from the y-axis; in this example, 0.50. This number is multiplied by the number of hours from Step 1.

Step 4: Find the Number of Starts Derating.

Approximate the number of starts that the microturbine will have in a one-year period. Find this number on the x-axis on Figure 11-3 and read the corresponding value from the y-axis. This number is multiplied by the number of hours in Step 2. In this example, 200 starts per year corresponds to 0.98.

Step 5: Calculate Lifetime of Battery.

Multiply the number of hours from Step 1 by the derating factors from Step 3 and 4. The result is the number of operating hours expected to battery end of life.

Expected life = 26,282 hours x 0.50 x 0.98 = 12,878 operating hours

Note that the expected battery life should not be more than 20,000 operating hours or 3 years elapsed time for scheduled maintenance purposes, even if the microturbine is used for standby or in a Dual Mode application.

Figure 11-1 provides an estimate of battery temperature rise as a function of size and frequency of repetitive load transients.

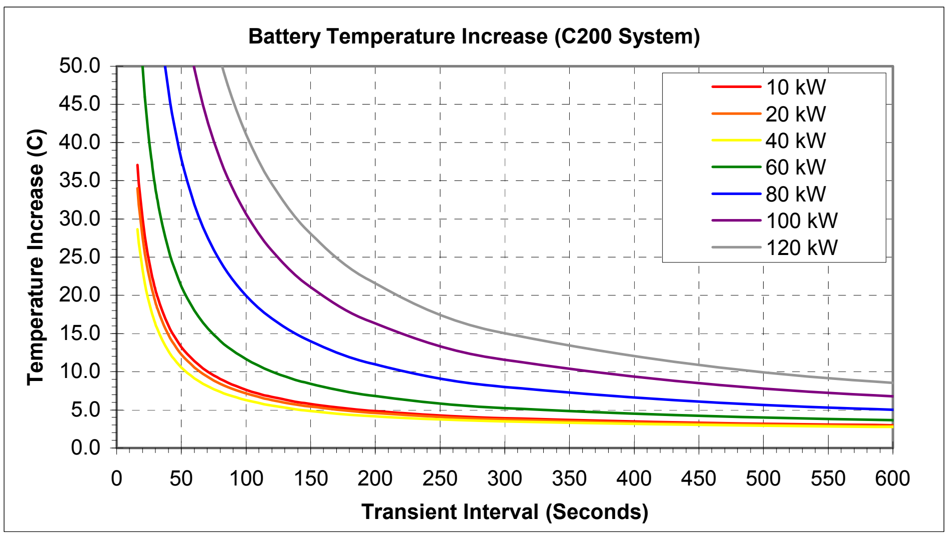


Figure 11-1. Battery Temperature Increase due to Load Transients

Figure 11-2 shows the appropriate derating factor for a given ambient temperature. The battery temperature during cycling should be estimated by adding the value obtained from the appropriate temperature increase chart, and the ambient temperature.

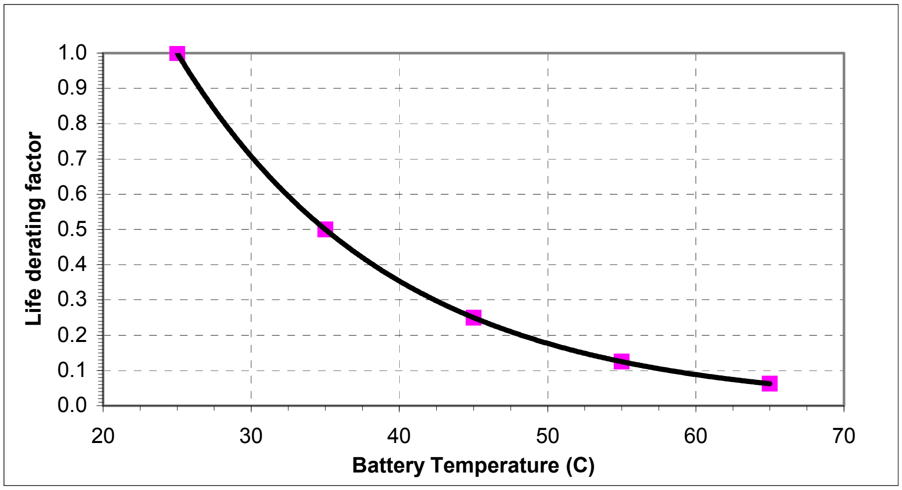


Figure 11-2. Temperature Derating for Battery Life

Figure 11-3 shows the appropriate derating factor for the number of starts per year. To find the derating, find the number of starts in one year on the x-axis, and follow the curve up to the line. The derating can be read from the y-axis.

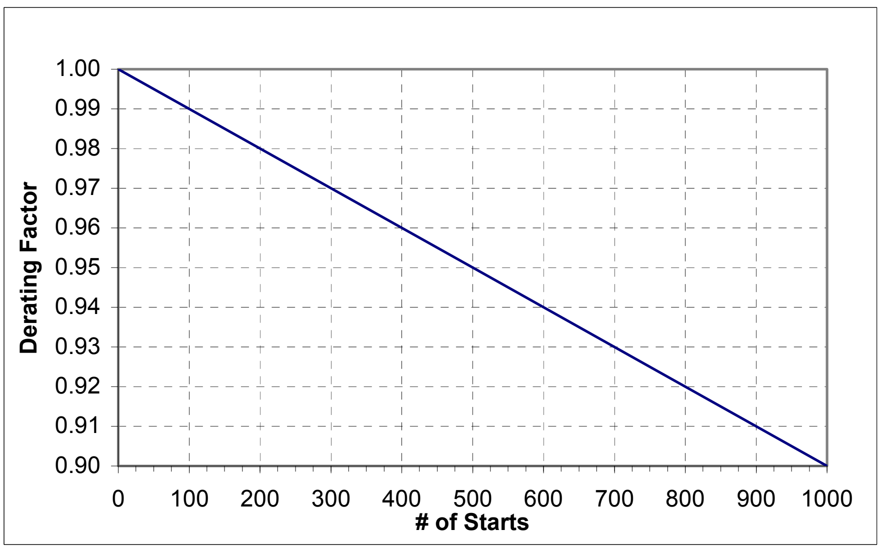


Figure 11-3. Derating for Number of Starts per Year

CHAPTER 12: INSTALLATION

Introduction

This section describes some example applications of the C200 microturbine including external equipment in a variety of power applications, as well as a subsection on the electric utility interconnection process.

Example Applications

Grid Connect Operation - Connection to a Utility System

Grid Connect operation mostly entails generating power in peak-shaving or base-load applications, displacing grid-supplied electricity when generation on-site can be done more economically, and in many cases more efficiently and with fewer emissions than electricity generated at a central plant.

Inverter-based technology allows microturbines to use grid voltages as a reference for power production as a current source. Seamless operation with the grid, with unity power factor and power ramping capability, helps customers meet load profile requirements as well as relieves strain on the grid distribution system while reducing grid heat losses.

Capstone microturbines are designed to safely produce power in parallel with an electric utility. Relay protection functions required for safe interconnection are built-in microturbine features, accommodating flexibility for a range of voltage and frequency settings. Field adjustable settings accommodate safe fault clearance at specific multiphase fault conditions.

Figure 12-1 depicts a typical Grid Connect installation.

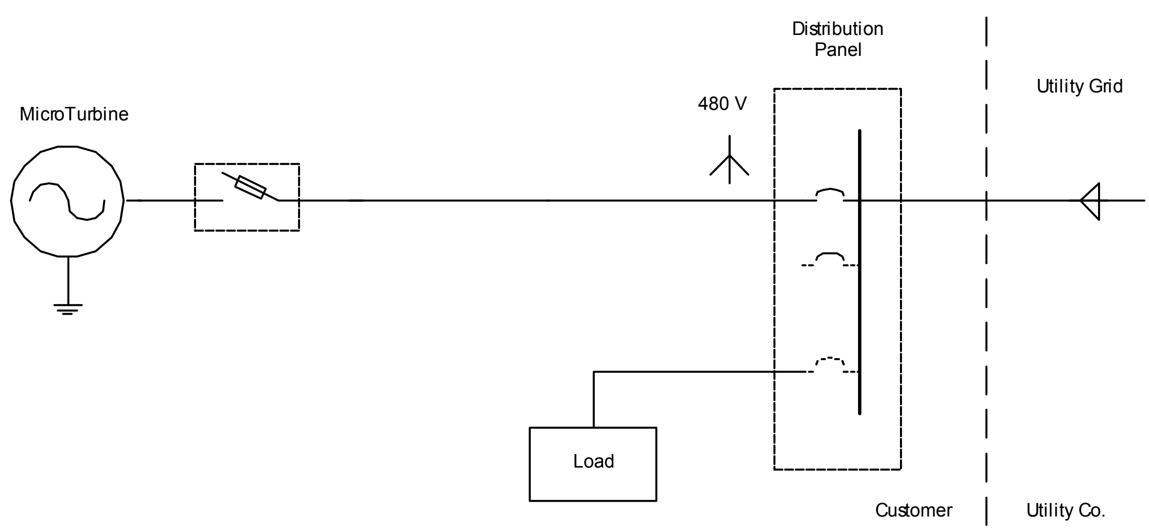


Figure 12-1. Grid Connect Operation

Grid Connect operation may be enhanced using a power meter to provide power flow signals to the microturbine.

In grid-parallel applications with variable electric loads, economics and/or utility restrictions may require that no power, or limited power, be exported to the utility. This requirement can be met using an external power meter, as shown in Figure 12-2.

Using a power meter's signals, a microturbine can dynamically adjust its output power level to ensure that limited or zero power flows back to the utility. This application is called 'Load Following'. For details on setting up a power meter, refer to the Chapter 10: Communications - External Power Meter Inputs in this document.

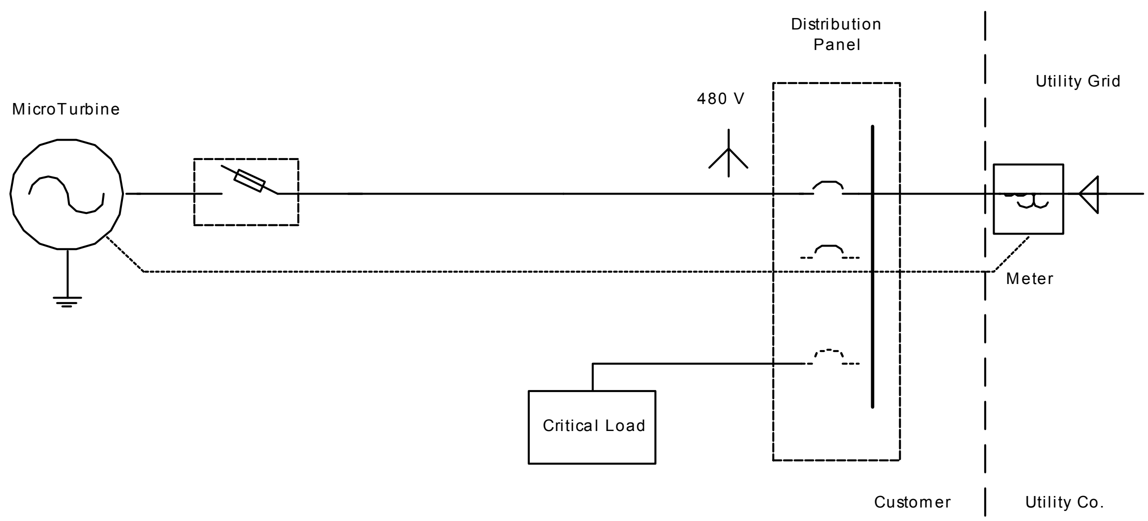


Figure 12-2. Grid Connect, Load-Following Operation Using a Power Meter

Stand Alone (Remote) Operation – Microturbine as Sole Power Source

In Stand Alone mode, the microturbine solely supports the load, providing required voltage, active and reactive power. Stand Alone capable microturbines are equipped with a battery and battery controllers. The battery is used for both starting the microturbine and supplying transient energy to connected loads.

Figure 12-3 shows a typical remote power diagram.

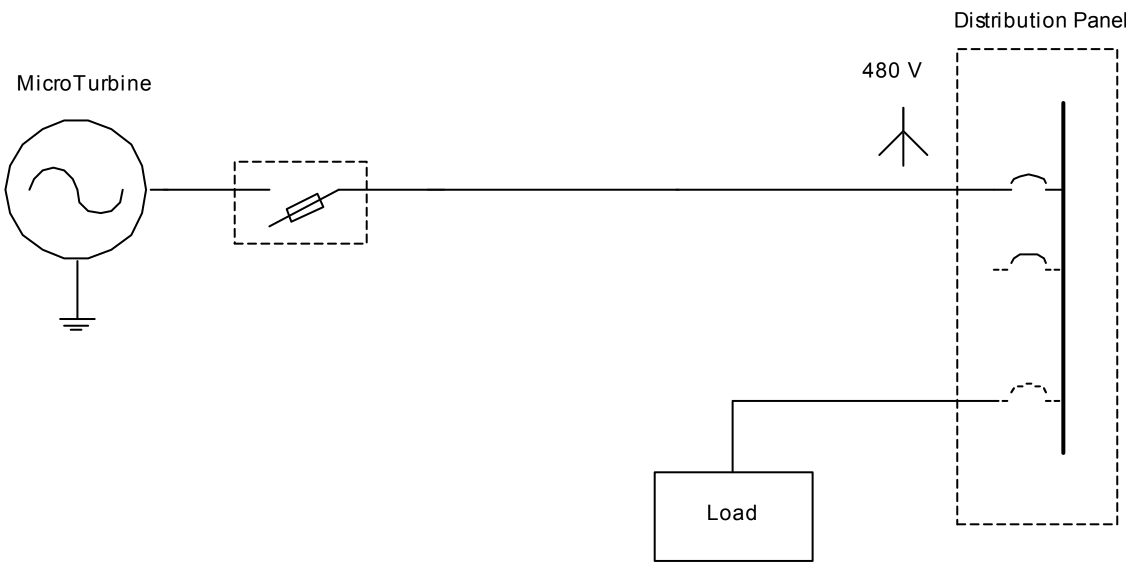


Figure 12-3. Stand Alone (Remote) Operation

Dual Mode – Microturbine is Both Grid Connect and Stand Alone

The term 'Dual Mode' refers to a microturbine's ability to operate both in parallel with a commercial utility or isolated from the utility in Stand Alone mode. Manual transfer between these modes of operation may be accomplished with a manual switch. Automatic or manual transfer may also be accomplished using a Capstone Dual Mode System Controller (DMSC). In cases where the load cannot tolerate any interruption, a UPS is used upstream of the critical load.

Figure 12-4 depicts a typical dual-mode configuration.

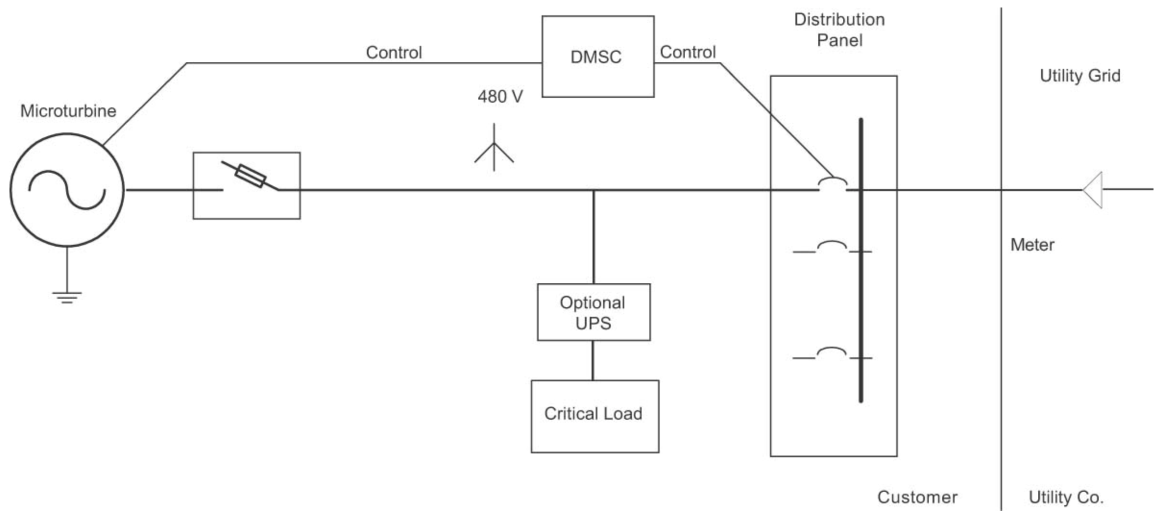


Figure 12-4. Dual Mode Operation

The DMSC serves as an intertie disconnect between the grid and the load. Any load downstream of the DMSC is termed the critical or protected load.

The critical load may be supplied from either:

- Commercial Utility (power company grid or line power)
- Both utility and microturbine operating in parallel (Grid Connect, or GC)
- Or the microturbine by itself (Stand Alone, or SA).

The transfer is initiated by:

- An undervoltage relay, built into the DMSC, in case of the grid outage, or
- Manually, by operator via the DMSC's front panel.

In Grid Connect mode, when a grid outage occurs, the DMSC circuitry senses the outage and opens a motorized switch or circuit breaker, isolating the microturbine and load from the utility. The microturbine may be configured to transition automatically to Stand Alone mode and resume power production, upon isolation from the utility.

The load experiences a power outage of a maximum of 10 seconds during such a transition. When the grid returns to normal operation, the DMSC will signal the microturbine to resume Grid Connect operation and will close the utility line circuit, supplying power to the load. When utility power is restored, the loads will return to the grid within five (5) seconds. The microturbine may be operating in a “Hot Standby” mode for up to 30 minutes, to be sure the utility voltage remains stable before reconnecting in Grid Connect mode.

Reliability Operation, Isolated – Microturbine as Grid or Prime Power Source

Microturbine operation may be completely isolated from the utility by means of an Automatic Transfer Switch (ATS). Several operating modes are possible using an ATS, each mode having different performance characteristics. In all cases, the schematic is generally the same.

The differences lie in whether the grid or microturbine is configured as primary power, and how the microturbine is configured to operate. In cases where the load cannot tolerate any interruption, a UPS is used upstream of the critical load.

Figure 12-5 depicts a typical configuration using an ATS.

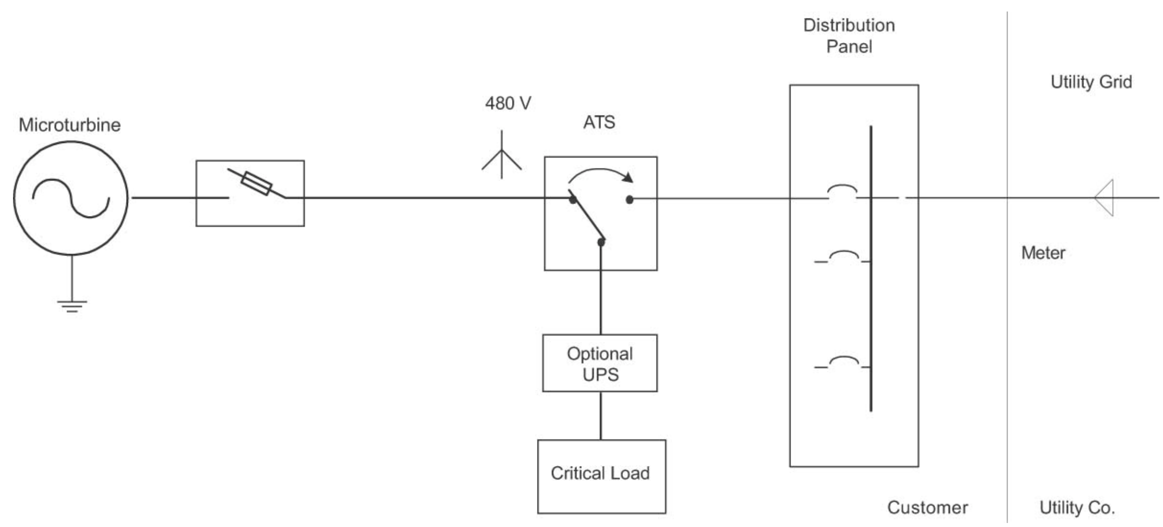


Figure 12-5. Isolated Operation

Table 12-1 outlines various operating modes possible using both Dual Mode System Controllers and transfer switches, with performance characteristics.

Table 12-1. Mode/Configuration Performance Comparison

Mode of Operation vs. Interruption	External Equipment	Prime to Backup Delay	Backup to Prime Delay
Microturbine as Prime* or Standby, plus UPS. MT can operate in Grid Connect mode as prime, peaking or standby; grid failure initiates MT shutdown/restart, batteries ride through event.	Battery UPS	None	None
MT Grid Connect and Stand Alone* MT runs grid connected, shuts down and restarts in Stand Alone mode upon grid failure.	DMSC**	<10 sec***	<5 sec
MT Stand Alone Prime, Grid as Backup* MT provides prime power, with ATS switching to utility only if MT goes offline.	ATS	<5 sec	<5 sec
Grid Prime, MT Standby MT runs only when utility fails, in Stand Alone mode	DMSC** or ATS	<6 min***	<5 sec
Grid Prime, MT idling Stand-Alone MT idles in isolated Stand Alone mode (load state), providing power to the load only during grid failure	ATS	<5 sec**	<5 sec

*Co-generation (exhaust utilization for heating, drying, absorption chilling) is possible with continuous/extended operation.

**Capstone auto-switching Dual Mode System Controller allows better load matching than an ATS, as MT power in excess of the critical load can flow to non-critical loads upstream of the DMSC. ATS does not allow Grid Connect operation, or the utilization of excess MT power. However, ATS transfer times are faster, and a utility interconnection agreement may not be required.

***Assume microturbine internal battery state of charge >60%.

Single Phase Applications

In applications where the connected load is single phase, there are several ways to convert the microturbine's three-phase output to single-phase. Note that this is only applicable to Stand Alone applications.

120-240 Volt

The most useful and recommended way is called a Zig-Zag connection (see Figure 12-6), utilizing three single-phase transformer banks, and is shown below for several applications. The 480/120-240 VAC topology produces a center-tapped 240 VAC voltage source. Two sources of 120 VAC power are available on either side of the center tap. Note that the 120 VAC power sources are 180° apart. The 240 VAC source may be loaded to 134 kW or each 120 VAC source may be loaded to 66 kW individually for a model C200.

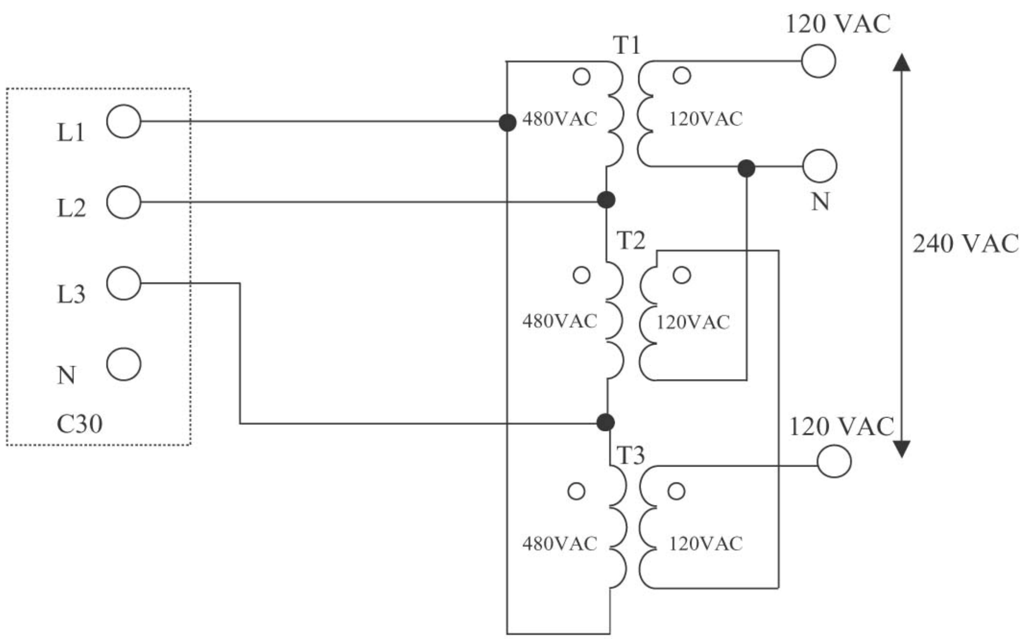


Figure 12-6. Zig-Zag Connection

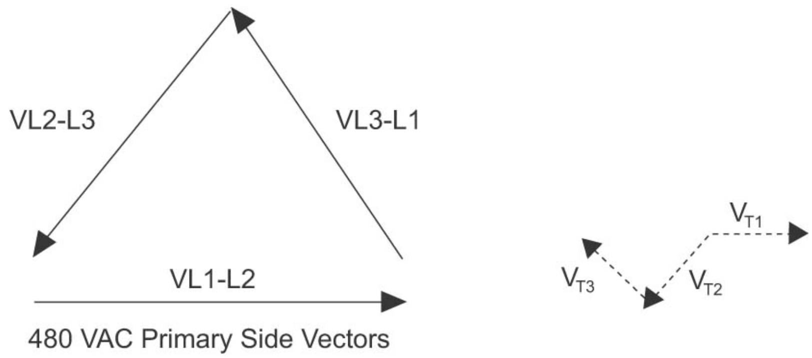


Figure 12-7. Zig-Zag Vector Diagram

Each transformer in the zig-zag connection must be rated for 67 kVA. The utilization factor for the set of 3 transformers is 66.7%. The utilization factors of the individual transformers are:

UF_{T1} = 100%

UF_{T2} = 50%

UF_{T3} = 50%

Example: In a typical application 134 kW of power may be delivered to a 120/240 VAC load. The individual loadings are:

Microturbine Power = 134 kW

T1 = 67 kVA

T2 = 67 kVA

T3 = 67 kVA

Phase L1-L2 Power = 67 kW

Phase L1-L2 VA= 67 kVA

Phase L2-L3 and L3-L1 Power = 67 kW

Phase L2-L3 and L3-L1 VA = 67 kVA

120-208 Volt

Two single transformer banks, 480/120 VAC can be connected to produce 120 VAC and 208 VAC, as follows.

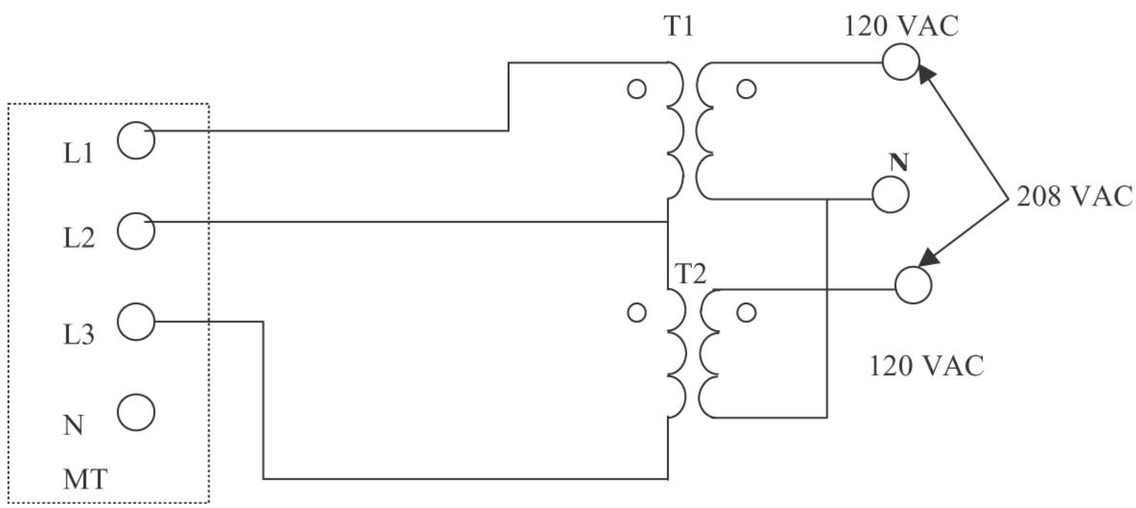


Figure 12-8. 120/208 VAC Single-Phase Diagram

In all above cases, it is only possible to draw 2/3 of the microturbine's maximum power rating.

NOTE	Relay protection functions in the microturbine do not allow grid-parallel operations in any of the above single phase applications.

Full Power

When a single-phase load can be distributed between three mutually exclusive electric panels, full power output can be achieved.

The following example illustrates single-phase configuration for full power utilization, with the output circuits, at 67 kW each. This example is essentially a three-phase application, where the phases are isolated. Phases can be up to 100% imbalanced and can be grid connected.

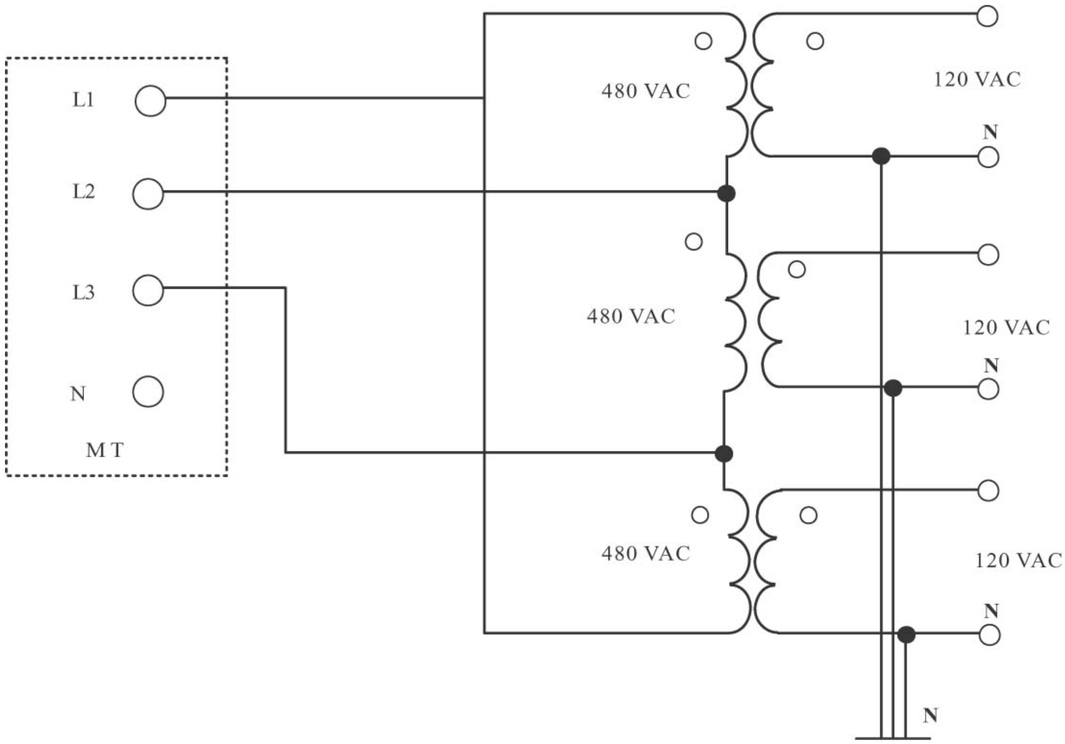


Figure 12-9. Full-Power Output via three (3) Isolated Single Phase Loads

Special Applications

Dual Mode Operation

A Capstone microturbine can be used as an alternative power source to the grid, supplying a critical load. Automatic or manual load transfer from and to a utility source can be accomplished by either traditional auto-transfer switch, or by the Capstone Dual Mode System Controller (DMSC), serving as a transfer switch and also acting as intertie disconnect between the grid and the load. An intentional island will be created when load is balanced with the microturbine output.

The critical load can be supplied from either:

- Power company grid (Line Power)
- Both, grid and microturbine in parallel, Grid Connect (GC) mode
- The microturbine, Stand Alone (SA) mode

The transfer is initiated automatically by:

- Undervoltage relay, built into the DMSC, in case of grid outage, or
- Manually, by operator on the DMSC front panel

In Grid Connect Mode (GC), a grid outage is detected by the DMSC undervoltage relay, which then isolates the utility from the microturbine by opening the DMSC motorized switch. When the grid returns to normal operation, the DMSC will close the utility line circuit, supplying power to the load.

In Stand Alone mode (SA), the microturbine solely supports the load, providing required voltage, active and reactive power.

Variable time settings accomplish coordination between DMSC and the microturbine protection devices. In case a grid voltage sag is in excess of set time (from 0.2 to 10 seconds) and voltage (from nominal to 50%), the DMSC undervoltage relay will cause the DMSC switch to open, isolating the critical load and microturbine from the grid. In case of a grid outage, the DMSC undervoltage relay will trip the switch immediately. In the latter case, the microturbine protective relays will shut down the unit(s), transferring from GC to SA operations.

The DMSC will control an electromechanical disconnect device (such as an electrically operated circuit breaker) which can be installed at various locations and voltage levels. In the shown example, the disconnect device is specified for 208 V at the Meter (PCC), and the MT voltage is 480 V.

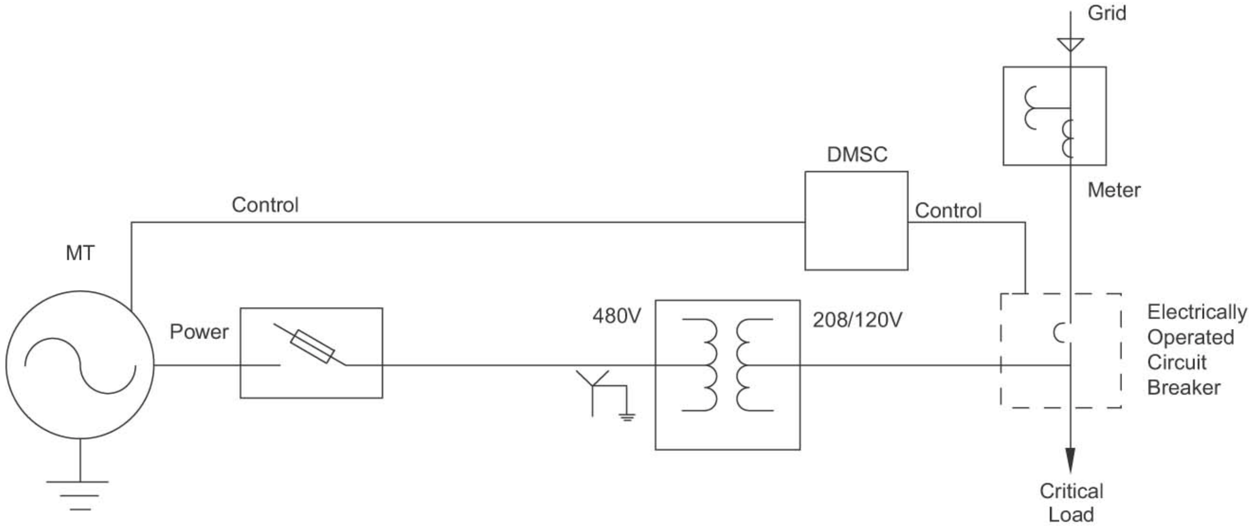


Figure 12-10. Dual Mode System Controller Connection Diagram

Power Meter Application

The microturbine is a demand-loaded system. The demand can be established manually, or by closed loop signals produced remotely. At any point of a connected power system, meter data communicated to the microturbine can be used to control real power.

In grid parallel applications with variable electric loads, there can be some restrictions for exporting electric power into the utility company grid. These restrictions can be related to non-power export mode or limited power export mode.

The microturbine can accommodate meter data, forward power flow (+PWR) and reverse power flow (-PWR) in form of signals at a rate proportional to the power flow at the control point to control power produced. The application is called “Load Following”.

In processing the information, the microturbine ramps up and down power output, keeping the required power level at the control point.

Power meters with KYZ outputs are commercially available from such vendors as Elster, Cutler-Hammer, GE, and Siemens.

Consideration shall be given to meters approved by the utility company for compatibility, when used at the Point of Common Coupling (PCC) or any other point controlled by the utility. In case of PCC, a meter can be rated and used as a revenue meter for accounting purposes.

Refer to Chapter 4: Operating Modes - Load Following and Chapter 10: Communications - External Power Meter Inputs in this document for more information.

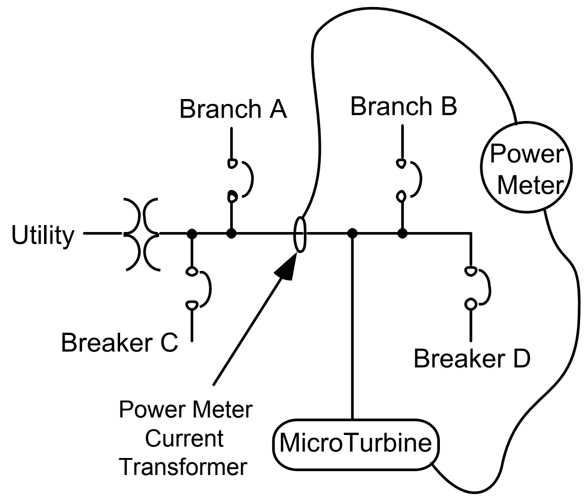


Figure 12-11. Power Meter Connection Diagram

Examples of Single Line Diagrams

The following illustrations are examples of single line diagrams.

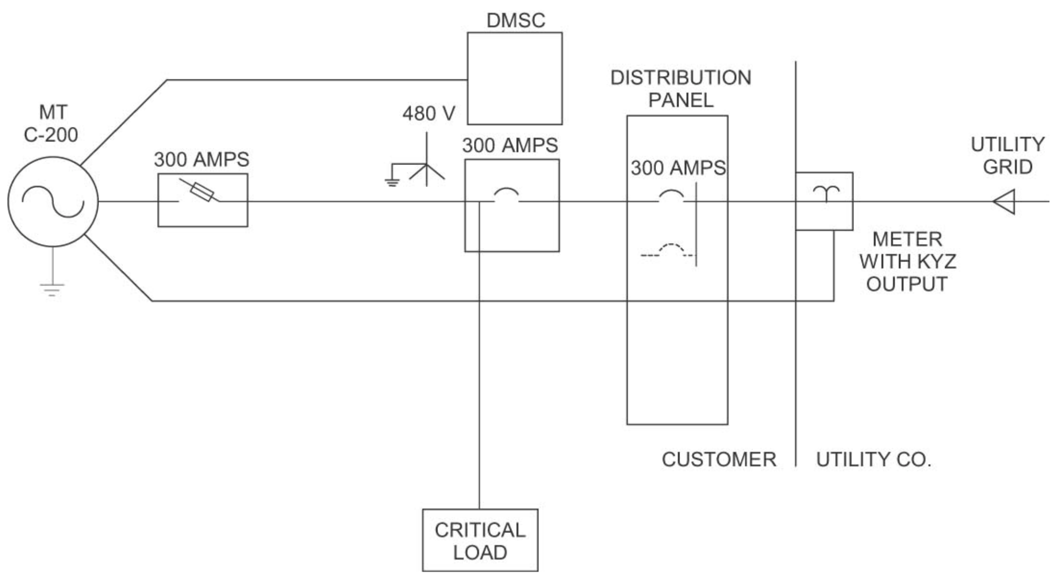


Figure 12-12. Single Line Diagram DMSC Example

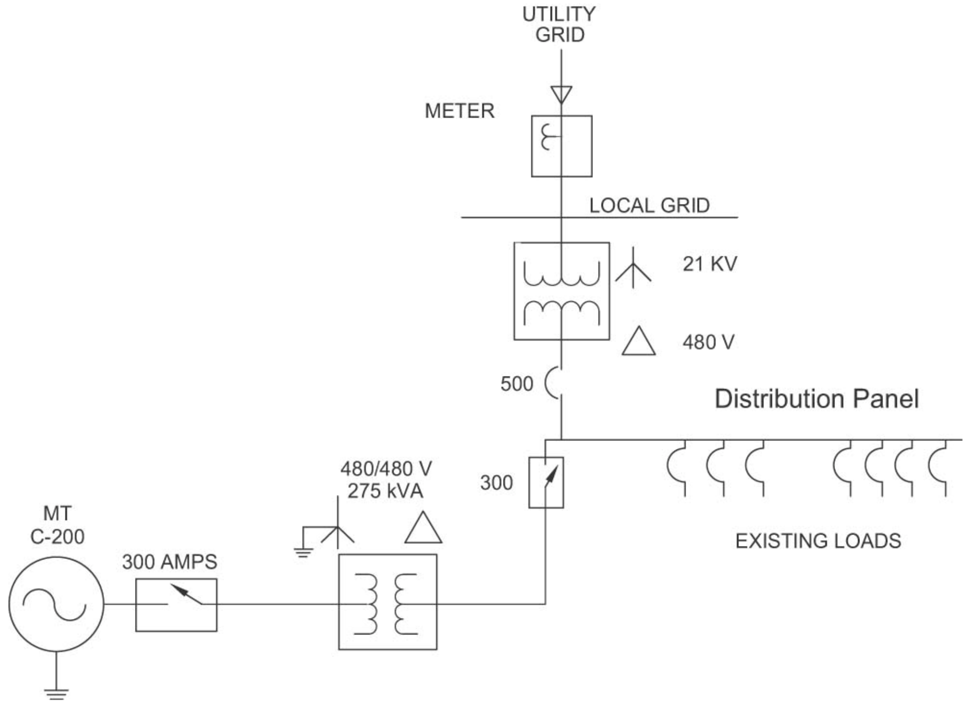


Figure 12-13. Single Line Diagram Grid Connect Example

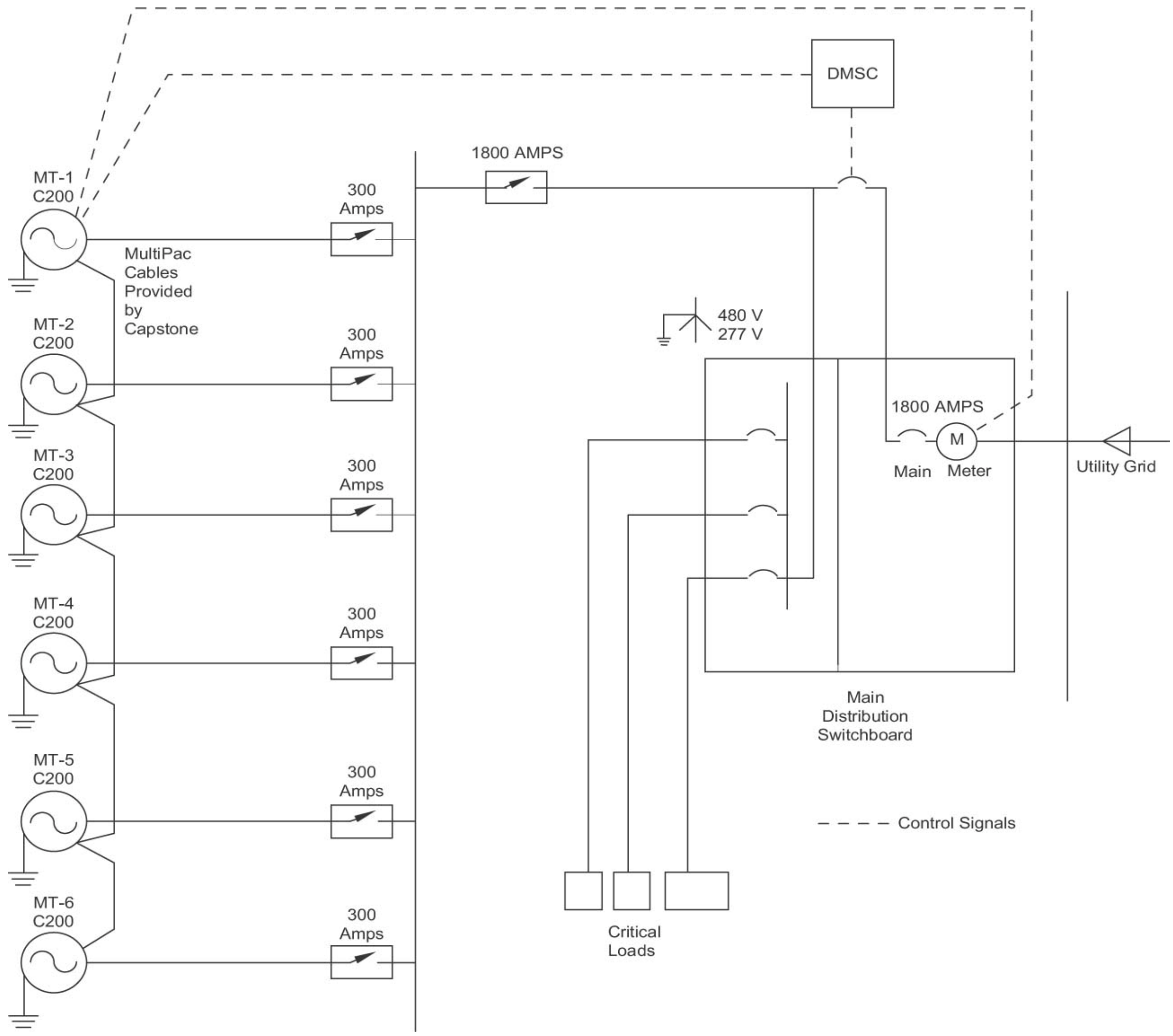


Figure 12-14. Single Line Diagram MultiPac Example

Utility Interconnection

Overview

Compliance with the requirements detailed in this document is essential to avoid problems that can affect the performance, life, reliability, warranty, and in some cases, the safe operation of the Capstone microturbine.

This section helps provide a standardized method for the interconnection of Capstone microturbine generators to the power grid. It is intended for use by Capstone distributors, buyers, consulting engineers, and utility companies when considering microturbines for utility grid parallel operations.

Due to technical advances in microprocessor-based power generation technologies with integrated relay protection functions, the Capstone microturbine generator is designed to be easily interconnected to the electric utility grid, supplementing utility provided electric power.

This section is specifically written to assist with the applications of Capstone products. It provides an overview of the interconnection process, based on utility interconnect requirements, institutional standards (IEEE 1547, UL 1741), and individual states' interconnect standards.

Interconnect Application Steps

Feasibility Study

Economic analysis, precluding further steps, should consider local utility tariffs or competitive prices, interconnection fees, permit approval activities, and consulting services for Capstone applications. These expenditures vary depending on the number of the Capstone units, geographical location, and the utility company. It should be recognized that Capstone units are certified for safe utility interconnection by Underwriter's Laboratories and by the states of New York and California. This interconnect certification means that the process can take less time than for uncertified generators, and should therefore be less costly to customers.

Factors impacting the interconnect process:

- Number of microturbine units proposed.
- Nature of the grid at point of connection.
- Power distribution or Point of Common Coupling (PCC) Voltage level.
- Requirements of the specific utility company.
- Electric Load to be supplied.
- Power Quality parameters such as voltage sagging, flicker, harmonic distortions.
- Other Distributed Generator or Generation (DG) systems operating on premises, in parallel with the grid.
- Utility and state regulations in the region.

Timeline

Though microturbine installation and interconnection with a utility for parallel operation should not present technical difficulties, experience has shown that utilities are sensitive to interconnection issues, due to their legal obligation to provide power to their customers, and require a thorough, methodical approach consistent with individual utility requirements. Establishing realistic timeframes and duties will facilitate smooth implementation, maintain good relations, and minimize potential delays.

Utilities and states are currently standardizing the interconnection process, reviewing the fee structure and setting up testing requirements. The process will establish procedures, timelines and all requirements for interconnection with the grid.

Depending on the complexity of the installation, the time to complete the interconnection after the initial meeting varies from two weeks in some states (CA and NY), to six weeks in other states (TX). This is in part due to the complexity of the interconnection and individual utility requirements for protective relay functions. Since the Capstone C200 microturbine has UL1741 certification, it is expected that in some cases the process can be ‘fast tracked’.

Technical factors that can impact the interconnect review process or determine which utility interconnect plan applies include the following:

- Distribution System at the Point of Common Coupling (PCC): network or radial.
- Size of generation facility in relation to the capacity of the utility feeder.
- Export capacity, as a percentage of feeder or line section peak load.

The interconnection standards are issued in the following states:

- California (also known as CPUC Rule 21).
- New York (Standardized Interconnection Requirements and Application Process).
- Texas (PUCT DG Interconnection Manual).
- Ohio
- Alberta, Calgary Canada.
- Illinois (ComEd’s “The DG Book”).

Configurations

The electrical output of the Capstone microturbine generator is 400 to 480 VAC 50/60 Hz, 3-phase, Wye, with a solidly grounded neutral. For other system voltages, transformation is required for microturbine Grid Connect interconnection with the power system or to support Stand Alone operation with customer loads.

NOTE	Microturbines can be connected and operated with an asymmetric configuration, such as 120/240 VAC, 3-phases, 3 or 4 wires

Project Design

A qualified engineering firm or a consultant, in compliance with local, state, and national codes and regulations, shall design an application which shall be in compliance with local, state, and national electrical regulations including the National Electrical Code (NEC). A one line diagram and a plan are minimally required in an interconnect application.

Interconnect Application

The typical application process consists of the following steps and can be more or less expanded based on state and utility requirements. Additional procedures can require additional screening and supplemental review, depending on the size of the DG application.

NOTE	Insufficient or incomplete information can cause a delay or rejection of the application.

- Initial Communication: inquiry for an application.
- Completion and submission of the Application forms, documents, and initial review fees.
- Upon acceptance, the utility company will prepare an Interconnection Agreement for execution by the applicant and the power company.

In addition, the following are normally required:

- A one-line diagram showing the electrical relationship and descriptions of the significant electrical components such as the primary switchgear, secondary switchboard, protective relays, transformers, generators, circuit breakers, with operating voltages, capacities, and protective functions of the Generating Facility, the Customer’s loads, and the interconnection with the Utility Distribution System.
- Site plans and diagrams showing the physical relationship of the significant electrical components of the Generating Facility such as generators, transformers, primary switchgear/secondary switchboard, and control panels, the Customer’s loads and the interconnection with the Utility Distribution System.
- Transformer information (voltages, capacity, winding arrangements, taps connections, impedance, etc.), if used to interconnect the Generating Facility with the Utility Distribution System.
- In the case of Dual Mode applications, it may be necessary to provide information on the transfer switching scheme or the Capstone Dual Mode System Controller, including capacity rating, technical and operational description.
- A disconnect device, with visible open circuit shall be provided and shown in the submittals, with specific brand, catalogue number, and rating, for each microturbine output line, for utility company approval as a safety means for preventing any feedback to the grid during maintenance or repair work on the grid, upstream of the microturbine.

Protective Relay Functions

The Capstone microturbine is equipped with built-in relay protection functions, which are performed by a microprocessor and other firmware. These functions are described in the Protective Relay Functions section of this document, and are only adjustable by a Capstone Authorized Service Provider.

Additional protective relay functions may be required by the local utility, and can be installed externally when needed; for example a reverse power relay at the point of common coupling with the utility or a ground fault relay (device 51N).

Application Review by the Utility Company

The utility will conduct a review of the design package to ensure that the plans/design satisfy the goal of attaining a safe, reliable, and sufficient interconnection and will satisfy the technical requirements for interconnection. In addition, some site-specific tests may be required prior to final authorization to interconnect.

Interconnect Agreement

The utility will provide the executable standardized interconnection contract, metering agreement, and power purchase agreement, appropriate for the DG application and desired mode of operation. These documents will clarify roles and responsibilities between the utility and customer and specify any additional power systems modifications, metering, monitoring, or protection devices necessary to accommodate the DG project in the utility distribution system.

The agreements will establish responsibilities, completion schedules, and estimated or fixed price costs for the required work. Execution of these agreements will indicate approval to proceed with the installation or to perform the construction work related to the interconnection.

Start-Up and Tests

During the start-up process, a utility company may request a demonstration of certain capabilities related to parallel operation with the grid. Such a demonstration can include: a response to a grid outage, demonstration of relay protection functionality and settings, and a response to some grid anomalies such as loss of phase, which results in two- or one-phase conditions operating in a three phase distribution system. Non-export of power can be required in some installations, which can be demonstrated by enabling the microturbine Load Following feature or using a separate reverse power relay.

In Dual Mode applications, islanding with isolated load and returning in parallel mode may be required to demonstrate and test the Capstone Dual Mode System Controller (DMSC).

These tests will require advance preparation including a written procedure and coordination with the utility.

CHAPTER 13: REFERENCED DOCUMENTATION

The following table lists applicable Capstone documentation.

Document Part No	Description
400008	C200 User's Manual
400011	Advanced Power Server User's Manual
410002	Fuel Requirements Technical Reference
410013	CRMS Technical Reference, User's Edition
410014	CRMS Technical Reference, Maintenance Edition
410049	Ethernet Converter Technical Reference
410065	Emissions Technical Reference
410071	Dual Mode System Controller Technical Reference
430070	C200 Troubleshooting Guide
440000	Standard Maintenance Schedule
460045	C200 Product Specification
480002	Landfill/Digester Gas Use Application Guide
480023	Advanced Power Server Technical Reference
523005	C200 Outline and Installation Drawing